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Preliminary Groundwater and Salinity Investigations in the Eastern Wheatbelt

3. Welbungin and Beacon River Catchments

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Disclaimer

The contents of this report were based on the best available information at the time of publication. It is based in part on various assumptions and predictions. Conditions may change over time and conclusions should be interpreted in the light of the latest information available.

Table of Contents

Tables

Appendices

1. Abstract

Drilling and geophysical surveys in the Welbungin and Beacon River catchments were conducted to determine the possible causes, nature and potential for the spread of salinisation within the region. The results suggest that deep sequences of sedimentary materials are recharged directly as a result of flooding and waterlogging adjacent to, and within the drainage lines. Recharge also occurs on the hillslopes. As a consequence of this, management systems adopted must control recharge and discharge in all parts of the landscape.

Water—tables show no obvious signs of a nett annual rise in the bores monitored in the valley floor, lower slope areas over the three year period (1986-1988). However, in the winter of 1989 and the summer of 1990 large storms raised the water-tables, which were already close the surface (< 2 m) in the lower slopes of both catchments. Groundwaters are extremely saline (< 8,000 mS/m), the sedimentary and saprolite aquifers permeable (hydraulic conductivity range 0.1-2.0/day) and the groundwater systems characterized by low, horizontal, hydraulic gradients (0.001 to 0.0001).

Future management systems should seek to decrease recharge by changing rotations and farm practices while increasing discharge by using trees, pumps and halophytes. Options are available for drainage, however, caution should be taken to ensure the projects are economically sound and disposal problems are addressed. A potential appears to exist for developing groundwater supplies in the area north of Beacon. This may provide both a useful water supply for livestock and lower groundwater levels in areas prone to salinity. Saltland agronomy is an attractive short to medium term option for the improvement of saline farm economics. Integrated catchment management is strongly recommended.

2. Introduction

2.1 Location

The Welbungin and Beacon River catchments are located 400 km NE of Perth, approximately 10 and 40 kilometers SE and NW, respectively from the town of Bencubbin (30°48’ S, 117°5l’ E) (Figure 1). The catchments drain towards the Yilgarn River to the south and form a part of the Swan-Avon drainage basin. The Welbungin catchment covers an area of over 15,000 ha and drains towards the major palaeodrainage system flowing south from the Beacon River catchment. The Beacon River catchment drains an area of approximately 130,000 ha.

The geology of the Bencubbin area is dominated by granitic and gneissic rocks of the Archaean eon. A northerly trending “greenstone” belt crops out south and west of the Welbungin catchment. The belt consists chiefly of banded iron formations and medium grained foliated amphibolites. Dolerite dykes trend east-north-east across the region and are considered to be Proterozoic, intruding both the late Archaean granitoids and mid to early Archaean greenstones along structural weakness (Blight et al., 1984). Extensive NNE-SSW faulting occurs throughout the district (CRA, pers. comm., 1988).

Deep weathering and subsequent lateritization of the bedrock materials is suggested to have occurred on a Mesozoic landscape (Van de Graaff et al., 1977) during the Tertiary period, 25-30 MYBP (Schmidt and Embleton, 1976). Continued weathering of the8e materials and consequent hillside erosion and valley deposition, have resulted in characteristic weathering depths of 30 to 60 m. Valley sedimentation is thought to have occurred primarily by sheet wash rather than major riverine transport processes, although alluvial sequences are common.

Figure 1.

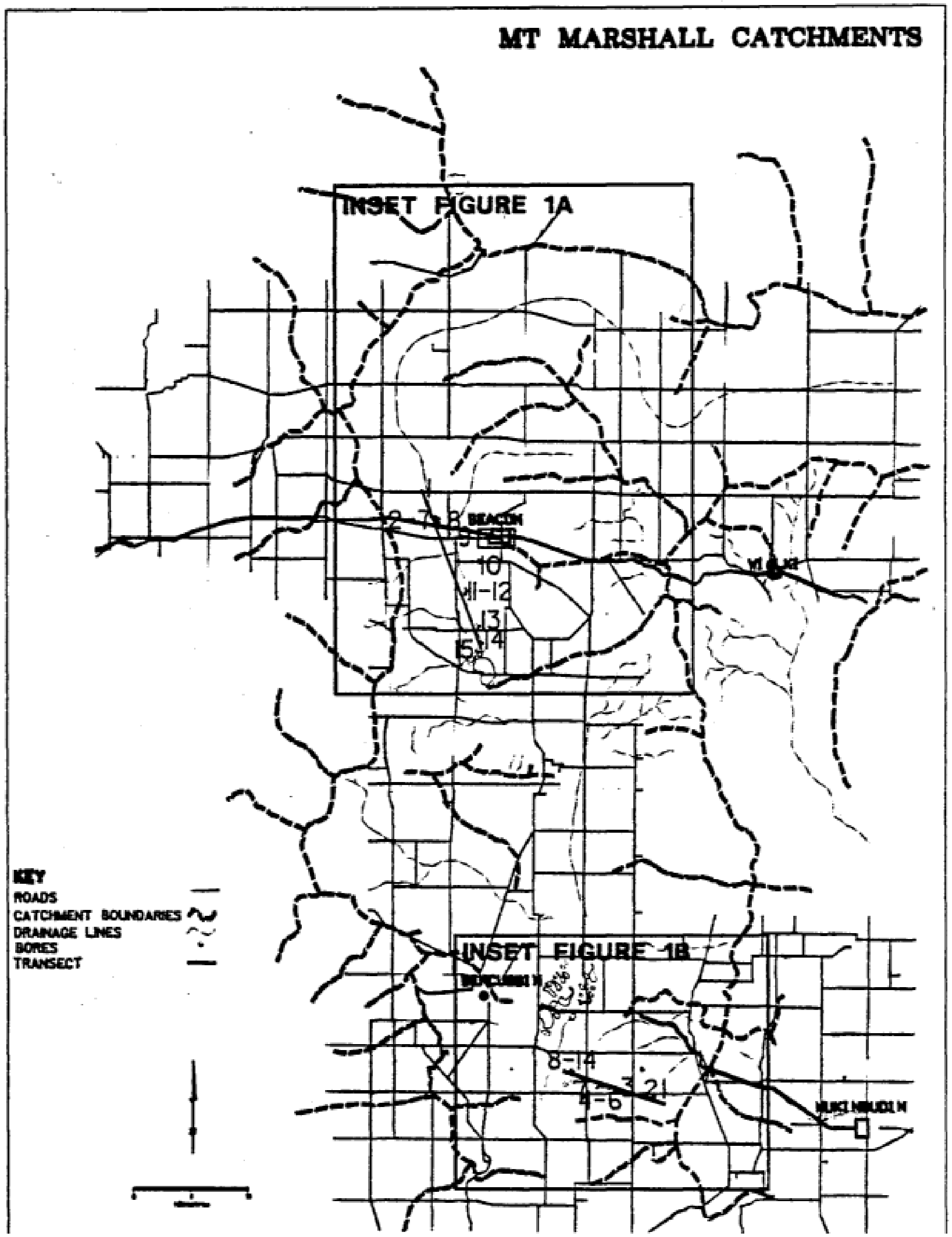

MT MARSHALL CATCHMENTS
INSET FIGURE 1A
INSET FIGURE 1B
BEACON
KEY
ROADS
CATCHMENT BOUNDARIES
DRAINAGE LINES
BORES
TRANSECT

Figure 1A

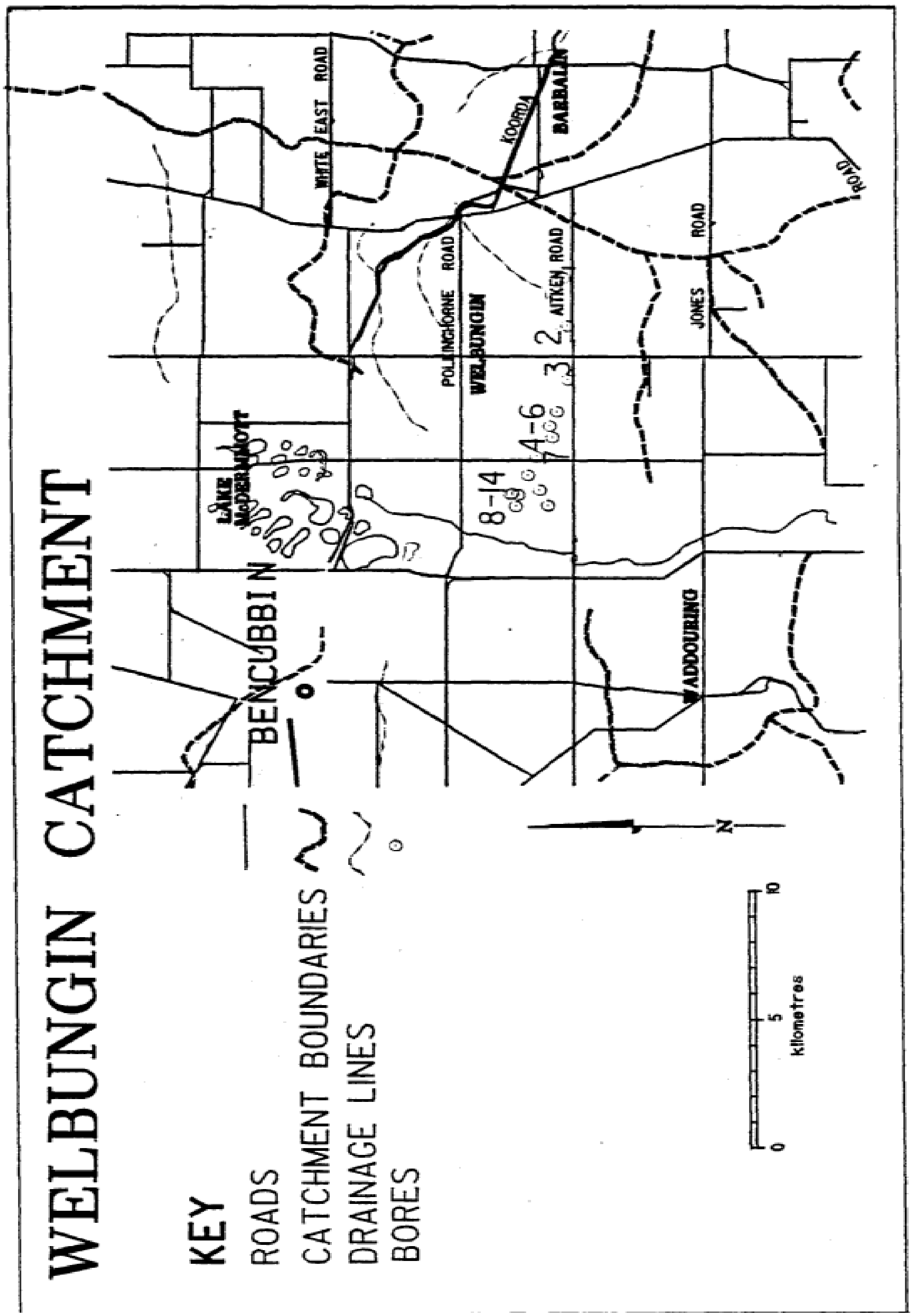
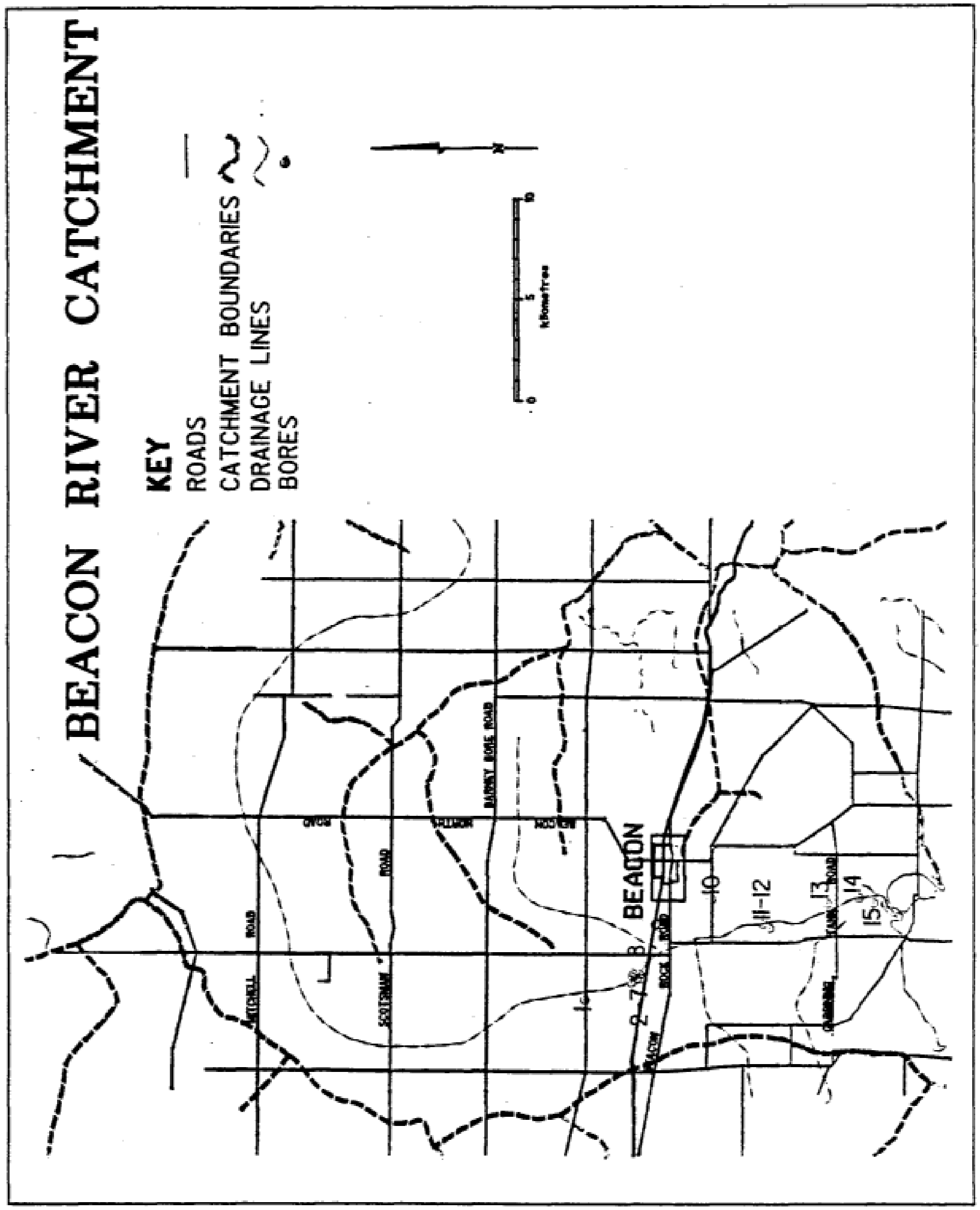

WELBUNGIN CATCHMENT
KEY
ROADS
CATCHMENT BOUNDARIES
DRAINAGE LINES
BORES
N
0
5
10
kilometres
WHITE EAST ROAD
KOORDA
BARBALIN
ROAD
AITKEN ROAD
JONES
POLLINGHORNE ROAD
WELBUNGIN
LAKE McDERMOTT
BENCUBBIN
WADDOURING
2
3
4-6
7
8-14

Figure 1B


BEACON RIVER CATCHMENT
KEY
ROADS
CATCHMENT BOUNDARIES
DRAINAGE LINES
BORES
BEACON

The major valley systems which drains the Beacon River and Welbungin catchments are characterized by Quaternary groundwater discharge complexes and playa lakes. These lakes act as the terminal points for runoff waters and are also usually groundwater discharge features. The dynamic nature of groundwater conditions responsible for lake formation during the Quaternary (Bowler and Teller, 1986) and dryer conditions in the Holocene, has resulted in some of the lakes being presently inactive groundwater discharge areas. Re-activation of these systems is currently taking place following land-clearing and agricultural development.

Rainfall records are available from the Beacon and Bencubbin townsites. Annual rainfall at Beacon and Bencubbin (1912—1988) is 314 mm and 321 mm respectively (Table 1). Rainfall is greatest during the winter months (~50%), however, high intensity rainfall events developed from cyclonic activity during summer are common. Floods have been recorded from major winter and summer rainfall events (eg. 1989—1990). Mean annual evaporation rates are of the order of 2,900 to 3,000 mm, which create an “effective rainfall” deficit during all of the months of the year (Table 1).

TABLE 1. Annual Rainfall and Evaporation Data (mm)

	J	F	M	A	M	J	J	A	S	0	N	D	TOTAL
Beacon	15	14	22	25	42	57	48	39	16	12	11	10	314
Bencubbin	15	21	24	23	38	57	46	30	21	16	13	13	321
Evaporation*****	451	389	341	211	131	84	91	114	149	249	317	24	2,953

***** Potential evaporation data come from Wialki (Bureau of Meteorology, 1988).

2.2 Aims and Objectives

The Beacon River and Welbungin catchment studies were undertaken with several objectives in mind. The projects were initially designed to describe the interaction between shallow groundwater levels and soil salinity.

However, they also provided an opportunity to look at the interaction of valley flooding, aquifer responses and processes of recharge and discharge. Regional groundwater observations networks also allow for the monitoring of long-term groundwater and salinisation trends to be based on rational grounds. The management of salinity was looked at from both the conventional integrated catchment systems approach and engineering orientated solutions approach.

The Welbungin and Beacon River catchments are typical of catchment-landform systems in the northern region of the eastern wheatbelt. A large flat valley dominates the Welbungin catchment, while the proportion of upland areas at Beacon is similar to the valley systems (including Welbungin) in the Merredin region. Soil-landform relationships described by Bettenay and Hingston (1964) are relevant to both of the catchments studied.

3. Materials and Methods

3.1 Drilling Investigations

Drill holes were installed using a rotary air-blast drilling rig. Groundwater monitoring was conducted using a total of 30 piezometers and observation wells throughout the study area (1986—1987). Drill sites were selected on the basis of soil-landform characteristics and elevation within the landscape. Drilling concentrated in the lower valley environment where the depth to saline groundwater was likely to be critical for agricultural production. A limited amount of drill hole records were also available from the Geological Survey of Western Australia (GSWA). Data on an additional 13 bores was obtained from this source and used to help determine the potential for groundwater use and associated influences as a method of mitigating dryland salinity. These bores were drilled over the period between 1972 and 1973.

Piezometers were constructed from 40 to 50 mm PVC tubing, using commercially slotted pipe over the lower two metres of the depth of installation. The tubing was lowered down the uncased hole immediately following drilling. A sand screen, comprising graded sands (1 to 3 mm diameter), was placed in the annulus alongside the slotted section. Several metres of bentonite and cement were located above this material to prevent contamination from the surface or from other groundwater. The remainder of the bore was then backfilled with drill cuttings to the surface and lined with concrete to protect against fire and stock damage.

Drill-hole cuttings (profile samples) obtained during the drilling operation were collected at one metre intervals and described on site. Description of the samples were carried out to assess their physical characteristics and likely origin (Appendix 1).

Initial development of the piezometers, to remove drilling contamination, was completed in the weeks following drilling. The development procedure consisted of frequent compressed air injections or water withdrawals from the piezometers until the casing was free of sediment and the water clear. The depth to the water-level within the piezometers was periodically (monthly) recorded during the years 1986 to 1990.

3.2 Geophysical Investigations

Two geophysical techniques were used to aid the interpretation of geologic features within the Welbungin catchment. Ground based traverses of the catchment using the magnetic and electromagnetic systems were conducted. The traverse lines are marked on Figure 1 and were carried out along the line of major surface drainage (creeklines). At both the Welbungin and Beacon River catchments, electromagnetic soundings were conducted at each borehole in order to estimate near surface (—lm) and subsoil (—6 m) salt storages.

3.2.1 Magnetic Method

A ground magnetic survey was carried out on a 12 kilometre line at Welbungin Catchment using a “Geometrics” G.856 proton precession magnetometer mounted on a two metre pole. A small (2,000 m) survey was also conducted at the Beacon Catchment. Measurements of the magnetic field displayed by the ground were taken every 20 to 50 m along the transect. In areas of increasing or decreasing magnetic activity measurement spacings were reduced to 10 m intervals. A base station was set up at the beginning of the day and returned to frequently during the survey to determine the extent of any diurnal magnetic drift. Surveys were conducted on days of low geomagnetic disturbance.

Magnetic surveys are capable of locating bedrock materials with different magnetic and mineralogic characteristics to the background materials.

Magnetic anomalies have been demonstrated to be primarily caused by basic intrusive (dolerite) dykes and amphibolites. These rocks are commonly found along zones of geologic instability such as structural faults and greenstone belts. The reader is referred to Engel et al. (1987) for a detailed account of the method and its application.

3.2.2 Electromagnetics

The electromagnetic terrain conductivity surveys were carried out using the Geonics EM38 and EM31 conductivity meters. These units consist of a transmitter and receiver placed at 1.0 and 3.5 m apart respectively. The EM38 has an approximate depth of penetration of 1 m while the EM31 is capable of measuring to 6 m (McNeill, 1981). Both instruments produce a primary electric current which is transmitted into the ground. A secondary current is subsequently received from the ground over the depth of influence of the different instruments. The actual depth of penetration is determined by the resistivity of the ground. The ratio of these fields is measured as a voltage in the receiver coil and displayed directly as electrical conductivity in milli Siemens per metre (mS/m). Conductivity is the inverse of resistivity and is used as an expression of the salinity of the soil profile.

The EM31 and EM38 were also used to determine the apparent conductivity (ECa) of soils adjacent to 15 boreholes at Beacon and 14 at the Welbungin catchments.

3.3 Soil and Groundwater Analyses

Soil cuttings obtained during the drilling were selectively submitted for electrical conductivity analyses of 1:5 soil water extracts. Fifty-six samples were analysed, twenty from the Welbungin catchment and the remainder from the Beacon catchment. Analyses were conducted by the laboratories of the Division of Resource Management, Department of Agriculture, South Perth.

Bore—water samples were collected from all of the piezometers which encountered groundwater. Samples were taken for electrical conductivity (EC) and subsequently converted to total dissolved salts (TDS) as milli grams per litre (mg/L) using Equation 1, derived from analyses of 107 of water samples taken throughout the eastern wheatbelt.

$$TDS = EC \text{ (at } 25°c) \times 6.5 \qquad (1)$$

Samples were collected from bores following repeated bailing of the bore and subsequent refilling from the aquifer through the screen. Analyses were conducted at the laboratories in South Perth and Merredin.

3.4 Hydraulic Conductivity

Hydraulic conductivities were measured using the methods outlined by Bouwer and Rice (1976). A 2 m change in the head of water was instantaneously created in the bore using a sealed aluminium cylinder. Head measurements were taken over the recovery period and a slope estimate derived from the early time (—10 minutes) data.

4. **Results and Comments**

4.1 ***Drilling Information***

Rotary air-blast drilling was conducted in both catchments during February and March 1986. A total of 150 m and 200 m were drilled in the Welbungin and Beacon River catchments respectively. The GSWA data provided an additional 289 m, however, none of these bores were logged in detail. Boreholes were drilled into deeply-weathered basement materials in many cases, however, the majority were screened in sedimentary sequences. For convenience, the description of the catchment lithology and hydrogeology will be broken into individual catchment sections.

4.1.1 Lithology

The nature and distribution of the weathered gneissic and granitic materials overlying bedrock were described from soil cuttings retrieved during the drilling programme. A diagrammatic summary of the drilling results is shown in Figures 2 and 3. The diagrams from both catchments show two distrinct lithologic units. The first consists of various sequences of alluvial, colluvial and aeolian sediments deposited in the valleys during the early Cainozoic and perhaps Quaternary geologic periods. Sediments were found to occur to depths of up to 18 m in the central valley area, however, they appeared to thin out rapidly towards the valley flanks. Below the sedimentary materials, deeply-weathered and chemically altered bedrock was encountered. This material consisted of variously indurated mottled and pallid sandy clays. Massive siliceous horizons were often encountered and occasionally represented an impenetrable barrier to continued drilling. Saprolite grits were found at the base of the weathering profile in the deep holes drilled to bedrock.

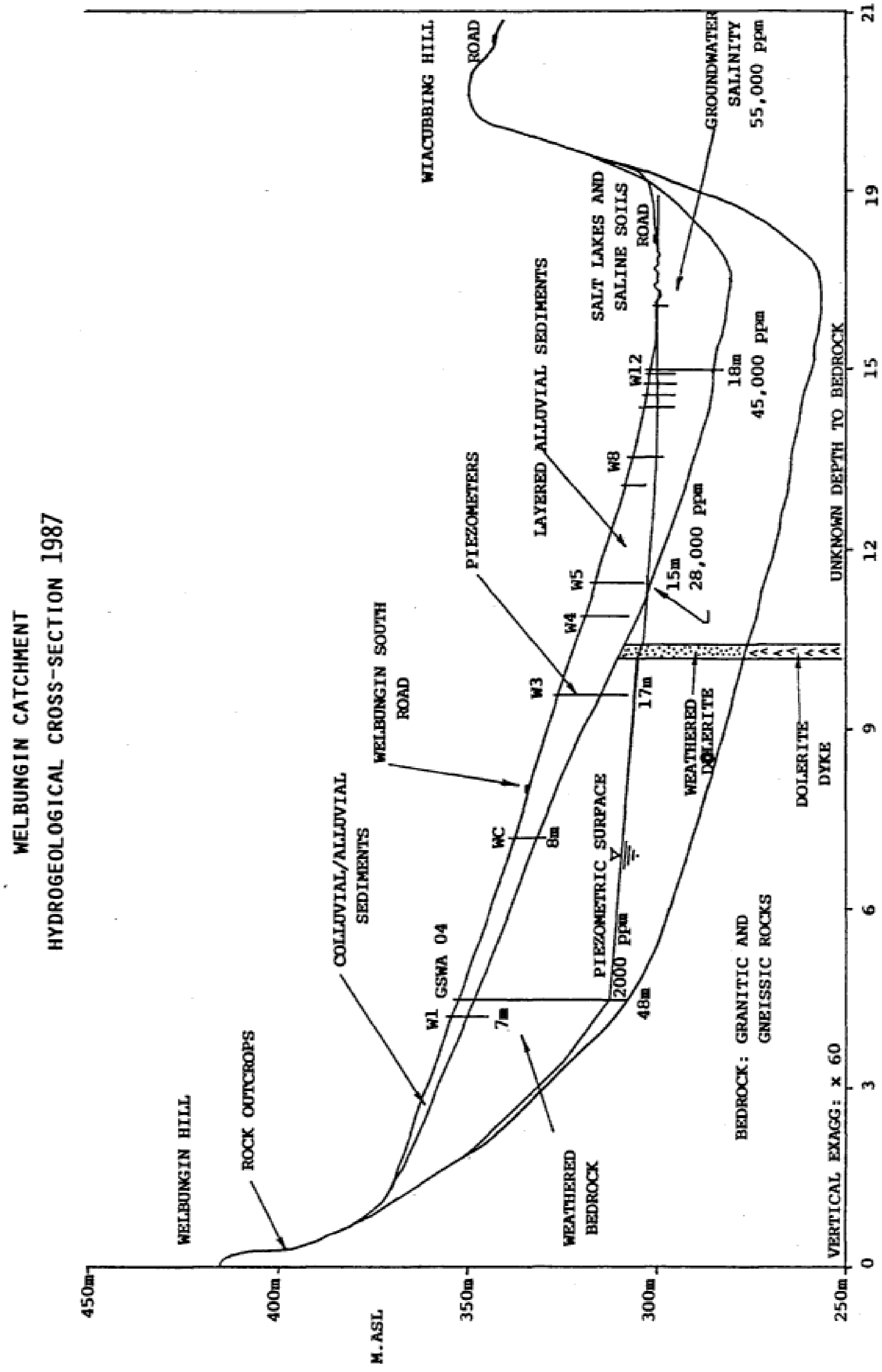

WELBUNGIN CATCHMENT
HYDROGEOLOGICAL CROSS-SECTION 1987
WELBUNGIN HILL
ROCK OUTCROPS
COLLUVIAL/ALLUVIAL SEDIMENTS
WEATHERED BEDROCK
W1
GSWA 04
7m
48m
PIEZOMETRIC SURFACE
2000 ppm
WC
8m
WELBUNGIN SOUTH ROAD
PIEZOMETERS
W3
17m
W4
W5
15m
28,000 ppm
LAYERED ALLUVIAL SEDIMENTS
W8
W12
18m
45,000 ppm
SALT LAKES AND SALINE SOILS
ROAD
GROUNDWATER SALINITY 55,000 ppm
WIACUBBING HILL
ROAD
WEATHERED DOLERITE
DOLERITE DYKE
BEDROCK: GRANITIC AND GNEISSIC ROCKS
UNKNOWN DEPTH TO BEDROCK
VERTICAL EXAGG: x 60
450m
400m
350m
300m
250m
M.ASL
0
3
6
9
12
15
19
21
KILOMETRES WEST

FIGURE 2

4.1.1.1 Welbungin Catchment

Drilling commenced downstream from the rocky upland region of the eastern part of the Welbungin catchment (Figure 2). The surface soils reflected the proximity to the bedrock outcrops, however, at depth the profile rapidly changed into hard, dry grey to red-brown sandy clays. Below this material the profile changed into red—brown to grey clayey sands and loamy sands and then into poorly-weathered granitic or gneissic material (saprolite). The change from weathered bedrock to sedimentary materials was delineated by a marked increase in the grain size of quartz and its angularity, the disappearance of feldspar and by the predominately sandy, to clayey, change in textures. The sedimentary zone was also characterized by layering associated with changing soil textures and commonly had the silicified materials at its base. Distinctive colour, texture and mineralogy changes were the best indicators of a change in lithology.

Lower in the catchment the surface materials became finer grained and silty, however, between WBO6 and WBO8, the surface materials consisted primarily of sands, deposited in a deltaic landform, to depths of 0.5 to 1.5 m. Subsurface sedimentary zones were dominated by heavy textured dry clays. Downstream, from WBO8 to WB14 colluvial, red—brown sandy clays graded into clayey sands from approximately 4.0 m near the interface, to 12-16 m at the base of the sediments. Weathered bedrock materials consisted of red and purple clayey sands to pallid sandy clays and were difficult to penetrate with the drill owing to secondary silicification and hardpan formations within the near surface zones. Heavy to medium textured clays were located below these materials to depth of 18.5 m at WB12. Deeper, the profile consisted of limited amounts of quartz and feldspar and was dominated by ferromagnesium minerals. Gneissic and migmatic materials were suggested to form the bedrock in this area.

Aeolian landforms occur along the western end of the Welbungin catchment adjacent to major palaeodrainage line. Gypsiferous and siliceous lunettes are common on the south—eastern edge of groundwater discharge, playa lakes. The lunettes are only poorly developed and show signs of wind erosion and soil movement well beyond the dune. Local deposits of mostly saline, fine grained lake parna occur as “morrel” soils south-east of the major systems. These soils are currently being reworked by erosive winds and are exposing saline subsoils. Soil salinity results in many situations in response to surface degradation rather than capillary transport of salts from the water-table. However, degradation may also expose the capillary zone.

Tertiary lateritization and subsequent weathering of the valley sides has produced extensive and deep deposits of yellow sandy earths. These soils occupy the upper to midslope area of the northern and southern catchment divides. Adjacent to, and below these soils are the deeply-weathered and kaolinized granitic and gneissic pallid, weathering and saprolite zones. In the eastern area of the catchment, large areas (> 3,000 ha) of bedrock materials outcrop. Limited weathering and soil development has produced arkosic sands and shallow, variably textured profiles.

4.1.1.2 Beacon River Catchment

Drilling in the Beacon catchment was limited to approximately 25 kilometres along the lower reaches of the Beacon River catchment (Figure 3). Drilling concentrated along the drainage line which terminates at a major playa lake (Jobs Lake). Fifteen drill sites were located in the region to determine the nature of the profiles and associated groundwater systems. Most bores were drilled until weathered basement was encountered and only one bore (BE13) was drilled to bedrock. An additional 13 bores, used to describe groundwater processes upstream (drilled by the Geological Survey of Western Australia) were not adequately logged and were therefore of little use when describing the lithology.

The catchment's profiles are characterized by the nature and depth of sediments found. The materials ranged from brown and red sands to sandy clay barns near the surface (0 to 3 m), to sands, clay sands and sandy clays to depths from 3 m to a maximum of 21 m. Surface, sandy zones were evident at some boreholes and had textures of loamy sands to well sorted, clean sands. The mean grain size of the sediments was typically 1 mm to 3 mm (diameter) and the grains were usually sub—rounded to sub—angular.

In the region of bores BEO1 to BEO7, surface sands were variably textured depending on proximity to the major drainage line. Bores located away from the depression showed clay sands relatively close to the surface (< 1 to 2 m), below red—brown sands at sites nearer the channel. At bore BEO3, next to the channel, the profile consists of three metres of well sorted sand, above red-brown to grey clayey sands to 16 m. Below 16 m a sequence of coarse textured, well rounded and sorted, medium to coarse grained quartz sands were noted to a depth of 21 m. At 21 m the profile changed rapidly to a hard, dense grey clay. This material comprised both coarse and fine grained quartz which was predominately angular to sub-angular. Large siliceous chips of the hardpan material were apparent in the drill spoil at 21 m.

At BEO2, located 50 m away from the saline channel, deeply-weathered materials were found at a depth of only 12 m. The large difference over this small distance suggests the existence of a "deep lead", a buried and ancient palaeochannel of the Beacon River. Drilling across the transect at BEO4 to BEO7 revealed that the sediments were greater than 12 m deep in some locations, although silicified zones often prevent deeper drilling to locate the existence of deeper, buried palaeocharinel materials. The estimated long section slope of the deep channel is shown as the (lower) dashed line in Figure 3. The "regional" depth of the sediments is shown by the other (upper) dashed line. More drilling would be required to accurately verify and plot these relationships than could be justified on the current project.

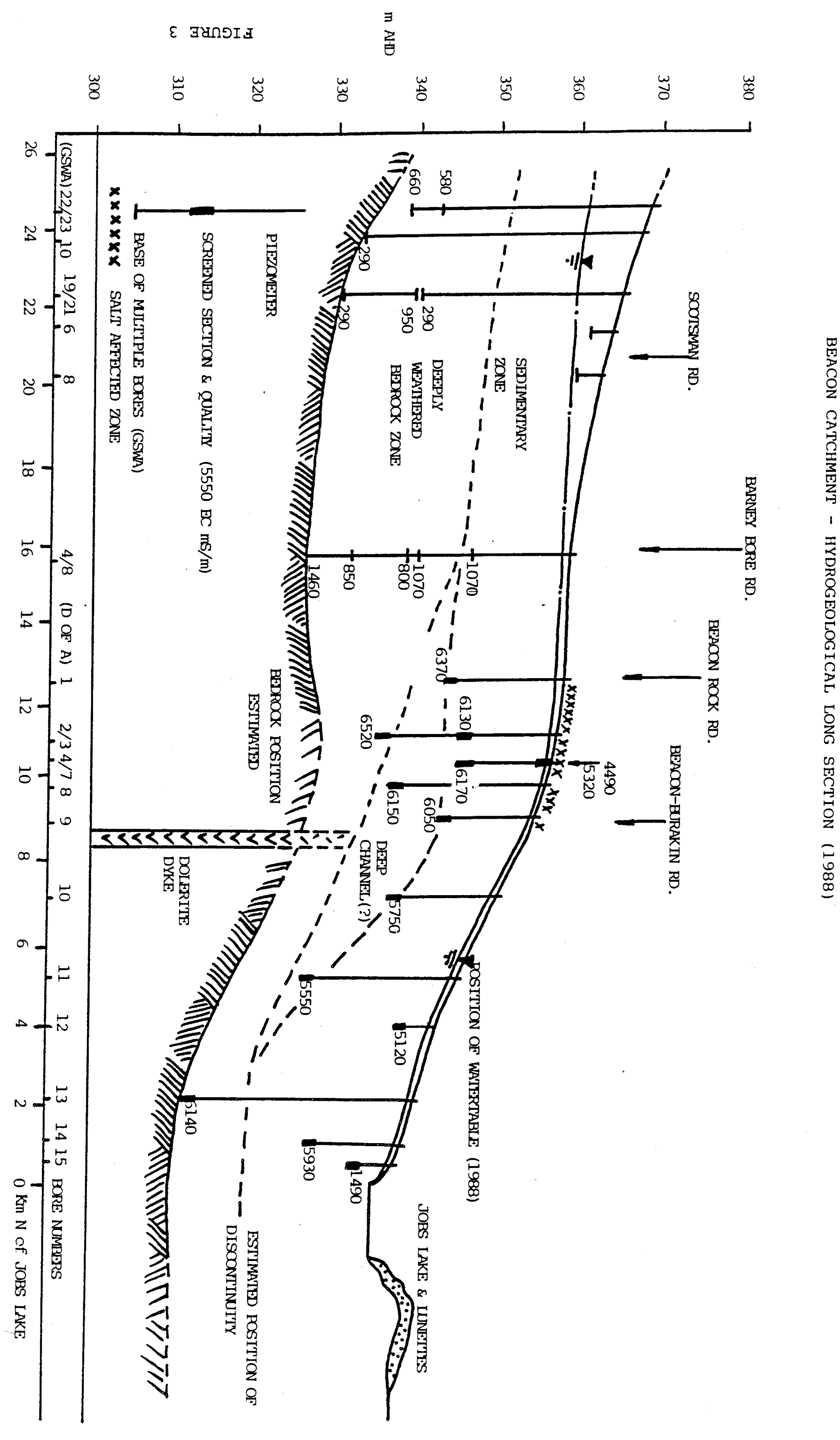

BEACON CATCHMENT - HYDROGEOLOGICAL LONG SECTION (1988)
m AHD
380
370
360
350
340
330
320
310
300
SCOTSMAN RD.
BARNEY BORE RD.
BEACON ROCK RD.
BEACON-BURAKIN RD.
SEDIMENTARY ZONE
DEEPLY WEATHERED BEDROCK ZONE
BEDROCK POSITION ESTIMATED
DEEP CHANNEL(?)
DOLERITE DYKE
POSITION OF WATERTABLE (1988)
JOBS LAKE & LUNETTES
ESTIMATED POSITION OF DISCONTINUITY
PIEZOMETER
SCREENED SECTION & QUALITY (5550 EC mS/m)
BASE OF MULTIPLE BORES (GSWA)
xxxxx SALT AFFECTED ZONE
580
660
290
290
290
950
1070
1070
800
850
1460
6370
6130
6520
4490
5320
6170
6150
6050
5750
5550
5120
6140
5930
1490
(GSWA) 22/23 10 19/21 6 8 4/8 (D OF A) 1 2/3 4/7 8 9 10 11 12 13 14 15 BORE NUMBERS
26 24 22 20 18 16 14 12 10 8 6 4 2 0 Km N of JOBS LAKE

FIGURE 3

However, if in the future groundwater pumping was seen as a major reclamation method, the existence or otherwise of these features should be researched. Electromagnetic induction methods, using the EM34, may reveal their location.

In the region to the south of the Beacon-Burakin Road the profile lithology became more variable, being dominated by alternate sequences of sand, but also including sequences of clay loam and clays. Site B512 for example, consisted of a zone of silty sands (below the surface sands to 1 in), underlain by a metre of heavy grey clay and grey-brown clay sands to 6 m. However, at BE13, the surface sands (1 m) and clays at 1—3 metres, were underlain by 19 m of red—brown medium to coarse sands. Weathered bedrock was encountered at 22 m, where the materials changed to the saprolite grits. This material comprised foliated zones of weathered gneissic material including large angular quartz and feldspar grains and an abundance of biotite. The material remained unchanged to 28 m where bedrock was located. A minor sequence (0.50 m) of pallid sandy clays were encountered at the interface between the saprolite and sediments. The sedimentary origin of the upper —20 m of these profiles is consistent with results from other catchments studied nearby (George, in prep., b). Geophysical logs (gamma—gamma) and mining company records from open cut gold mines in the district (Westonia - ACM) also reveal the ubiquitous nature of valley sediments.

Clearly defined aeolian landforms in the Beacon River catchment are not common in the region between BEO1—BE14. However downstream, south—east of the major playa lake (Jobs Lake), a series of concentric lunettes, several hundred metres wide and broad have developed. The lunettes are dominated by quartz sands and only minor gypsiferous materials are apparent. The lunettes stand about 7 m above the bake floor.

4.1.2 Hydrogeology

The groundwater systems within the catchments are described from the available drill-hole information. Supplementary data from records of the Geological Survey (unpublished bore records 1928-1973) were also used to aid interpretation of the hydrogeology of the catchments. Each catchment is discussed separately.

4.1.2.1 Welbungin Catchment

Groundwaters intersected during the drilling programme have been subsequently monitored and sampled over a period of four years. Figure 2, a diagrammatic-longitudinal section of the catchment summarizes the drilling information. Major features displayed in the figure are the low hydraulic gradients for flow; the rapid increase in salinity from the east to the west; the depth of the saturated zone and the location and effect (if any) of a large magnetic anomaly (dolerite dyke).

The low hydraulic gradients reflect the lack of significant recharge, the flat nature of the landscape and limited area extent of permeable soils around the rim of the catchment relative to the area of heavy textured valley soils. Hydrographs from bores which encountered groundwater clearly show the seasonal nature of recharge and suggest that significant recharge occurs adjacent to the palaeodrainage line in response to localized flooding and waterlogging.

Salinisation is apparent in soils adjacent to the drainage line where groundwaters are within 0.5 to 1.0 m of the soil surface. However, areas where the water-table is deeper (— 2.5 m), such as in the heavy textured “morrel” soils, may also allow the transport of salts to the soil surface. Conversely, “morrel” soils were noted by Bettenay et al. (1964) to be naturally saline and when disturbed by clearing, salts stored within the profile were redistributed and moved towards the soil surface.

The nature and response of the hydrographs (Figure 6) shows that recharge is seasonal and dependent on significant rainfall events to cause rapid and large rates of water-table rise (1989-1990). Limited vertical gradient development (< 0.01) also reflects the dominance of lateral flow within semi-unconfined sedimentary and semi—confined weathered zone materials. The potential for groundwater discharge is only apparent where the groundwater comes into contact with the capillary fringe. Figure 2 suggests that only the lower valley regions immediately adjacent to the palaeodrainage line has the immediate potential for salinisation. The depth to the water-table increases rapidly higher up the catchments, limiting the potential for the development of salinity during the next few decades. Water-tables were not observed to be rising systematically during the current monitoring period (1986-1990). The effect of the 1989-1990 period on the future of salinity can only be assessed after one to two more years of observations.

Hydraulic Conductivity

The hydraulic conductivity or permeability of materials at bores from WBO8 to WB14 are presented in Table 2. The data show a wide variation, with those bores installed in coarse sandy zones showing very high conductivities. The location of the screened zone is also noted.

TABLE 2. Hydraulic Conductivity of Welbungin Bores

BORE NO	HYDRAULIC CONDUCTIVITY (m/day)	SCREENED ZONE DEPTH (m)	SCREENED ZONE TYPE
WBO8	0.06	5.90 —7.90	Clayey Sediments
WBO9	1.10	3.70 —5.70	Sandy Sediments
WB1O	1.21	4.20 —6.20	Sandy Sediments
WB11	0.11	3.70 —5.70	Clayey Sediments
WB12A	0.88	3.70 —5.70	Sandy Sediments
WB12B	2.17	14.00 —16.00	Sandy Sediments
WB13	0.97	3.20 —5.20	Sandy Sediments
WB14	0.0009	4.40 —6.40	Clayey Sediments

***** Bores WBO1 to W507 are dry (see Figure 6).

4.1.2.2 Beacon River Catchment

Groundwaters encountered during the drilling of boreholes in 1986 have been monitored and sampled over a period of four years. Unlike the transect, or “fence” of boreholes drilled down the Welbungin catchment, only the lower 20 to 30% of the Beacon River Valley has been described. Interpretations of the available information are presented in Figures 3 and 4. The major features displayed by the figures are the very low groundwater gradients, high groundwater salinities, depth of the sandy sedimentary zones and location of a magnetic anomaly (dolerite dyke) parallel with the Beacon—Burakin Road. The diagrams give an exaggerated impression that the water—tables are extremely close across the lower catchment between bores BEO1-BE15. However, this is in part due to siting of most bores along an incised drainage line south of BEO8.

An attempt was made to diagrammatically represent information on the distribution of hydraulic head throughout the aquifer (Figure 4). The equipotentials shown in Figure 4 suggest groundwater flow is primarily horizontal, with upward heads below the saline zone in summer and strong upward heads below Jobs Lake. In winter, downward heads developed at BE05. The equipotential pattern downstream was estimated from limited data, although based on similar head distributions to those around lakes as discussed by Freeze and Cherry (1979) and others. The dolerite dyke observed in the western slopes of the catchment between BEO9-BE1O is shown as being dissected to the base level of the deep channel. The position of the bedrock ridge nearby is based on interpretation of the drill logs at BEO3 and BEO8. At these sites deeply-weathered materials were noted to be similar to those at BEll where bedrock was encountered about 10 in below the base of the sediments.

The hydrographs (Figure 6) show a clear response by the water-table and potentiometric surface during the winters of 1986, 1988 and 1989.

BEACON CATCHMENT - ESTIMATED DISTRIBUTION OF HYDRAULIC HEAD

(FLOW LINES NOT SHOWN)

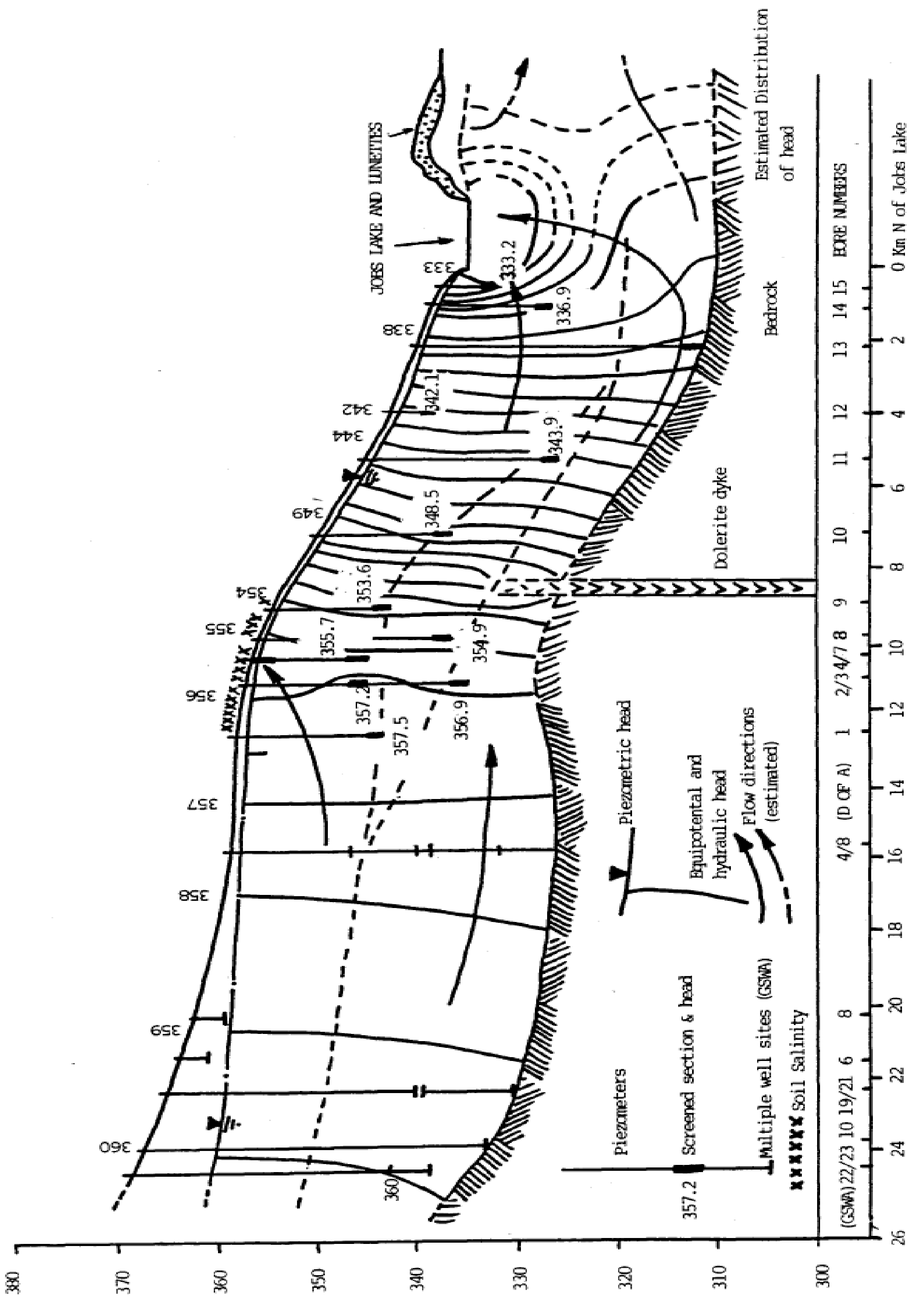


FIGURE 4

This coincides with higher than average rainfall and the incidence of localized flooding and waterlogging throughout the lower slopes near the drainage line. Intermittent river flows were recorded during these years. The source areas for these flows were noted to be structurally degraded paddocks adjacent to the drainage line, heavy textured hillslope soils and especially runoff generated from saline and waterlogged areas.

The rapid response of water—tables over the winter period during May to July coincides with periods of waterlogging, flooding, low evaporation and high rainfall. Responses were highest (0.5-1.5 m) in bores BEO9 and BE14 located south of the Beacon-Burakin Roads as a result of river flows and locally unco-ordinated drainage. Little or no response was recorded in water-levels in the low rainfall year of 1987. During the year bore levels continued to recess towards their static water—levels of 1985/86. In the bores installed upslope of the salt-affected area, north of the Beacon—Burakin Road, similar trends were noted. However, in these bores water—level responses also occurred in 1987. Observations of runoff were recorded in that year, however, flows did not reach BEO9 where water-level responses were smaller, and ranged from 0.3 to 0.5m.

The remaining bores were drilled in and adjacent to an area of saline soils between the regions mentioned above. Most of the bores showed water-level fluctuations of 0.2 to 0.5 m, however, the marked seasonal responses were not as obvious. In bore BEO6, water-levels showed a recession (0.3 m/yr) throughout the initial study period (1986-1988), rising in response to winter rains (1989). The bore is located near bull-dozer built interception banks and appears to be responding to discharge observed from them. Water quality measurements taken in the drainage line below this area show that saline water is leaving the salt-affected area due to direct runoff and drainage.

No apparent regional trends in groundwater levels can be observed from the four years of data. This is in part due to the variations in seasonal conditions, but mostly due to the short duration of the observation period and location of the bores. Closer inspection of the bore hydrographs however, shows that the recession curves do not always return completely to the previous position (BE12-BE15). Longer term monitoring is required to determine the significance of these observations. Observations relevant to the spread of salinity, management methods and fut4re monitoring programmes are discussed in Section 6.

Hydraulic Conductivity

The hydraulic conductivities of bores drilled in the Beacon River catchment are high in comparison with the results from other catchments drilled in the eastern wheatbelt, (George, in prep., b). However, much of the difference can be explained as many of the bores in other catchments are located in deeply—weathered, Archaean materials and not sediments. Table 3 summarizes the results of the slug tests used to estimate hydraulic conductivity.

The highest conductivities are associated with screened sections between 5—10 m below ground level, corresponding to sequences of coarse sands to clay sands. Lower hydraulic conductivities occur within the deeply-weathered materials and heavier textured sediments.

TABLE 3. Hydraulic Conductivity – Beacon River Catchment

BORE NO.	HYDRAULIC CONDUCTIVITY * (m/day)	SCREENED ZONE DEPTH (m)	SCREENED ZONE TYPE
BEO1	1.53	9.50 - 11.50	Grey sand
BEO2	1.51	9.50 - 11.00	Grey clay sand
8E03	0.50	19.00 - 21.00	Grey clay sand
BEO4	0.49	9.10 - 11.10	Grey clay sand
BEO5	0.68	9.30 - 11.30	Grey clay sand
BEO5	-	0.20 - 2.20	Grey clay sand
BEO5	-	1.50 - 3.50	Grey clay sand
2E06	0.98	5.10 - 7.10	Grey clay sand
BEO7	-	9.50 - 11.50	Grey clay sand
BEO8	0.09	15.40 - 17.40	Grey clay sand
BEO9	0.35	9.40 - 11.40	Red brown clays
BE1O	1.94	12.40 - 14.40	Grey clay sand
BEll	1.59	8.30 - 10.30	Grey clay sand
BE12	1.37	3.40 - 5.40	Grey clay sand
BE13	0.34	26.00 - 28.00	Saprolite grits
BE14	0.57	9.50 - 11.50	Sands
BE15	0.22	3.40 - 5.40	Clayey sand

* Bouwer and Rice (1976) slug tests used

4.2 Geophysics

4.2.1 Magnetica

Ground magnetic surveys were conducted in the Welbungin catchment to determine whether any major magnetic anomalies were affecting groundwater flow. Figure 5 shows the results of the transect survey and reveals the existence of a major magnetic anomaly (1,200 nT) located 4 km east of the drainage line.

The cause of the anomaly is suggested to relate to the intrusion of a dolerite dyke which strikes NNE-SSW across the catchment. An outcrop was observed in the south western area of the catchment, however, the orientation of the anomaly is uncharacteristic of the other, normally E-W trending dykes in the region. The anomaly may also relate to an intrusive greenstone belt or a major structural fault. Faults have been observed throughout the region, in a NNE-SSW strike (CRA, pers. comm., 1988).

No simple reason can be given for the magnetic anomaly located 9 km east of the major drainage line. However, as it does not have the characteristic peak and shadow effect of a dyke, a structural discontinuity or fault in the underlying bedrock is suggested.

Reference to the 1:250,000 Bencubbin geology map (Blight et al., 1984) reveals the existence of several major dolerite dykes. Of particular interest is a large dolerite dyke, exposed in outcrop between Beacon and Marindo, (adjacent to the Beacon-Burakin Road) which strikes E-W across the catchment between BEO9—BE1O. A small (2,000 in) ground based magnetic survey was conducted. The survey located the magnetic anomaly, validating ground investigations showing the position of the dyke.

The development of salinity north of the anomaly and valley incision to the south, also suggests that a structural, geological control is directly responsible for the current location of salinity. Other observations north of this area suggest that the regional drainage patterns converge above this point, adding to the premise that a structural control is operating. The dyke is clearly visible on aerial photographs (Photo 5018, Run 7, Jan. 7, 1982) and disappears below the valley sediments. The effect of the railway and road is unlikely to be significant as a causal factor for salinity. However, in terms of waterlogging and surface drainage downstream, such features may be important.

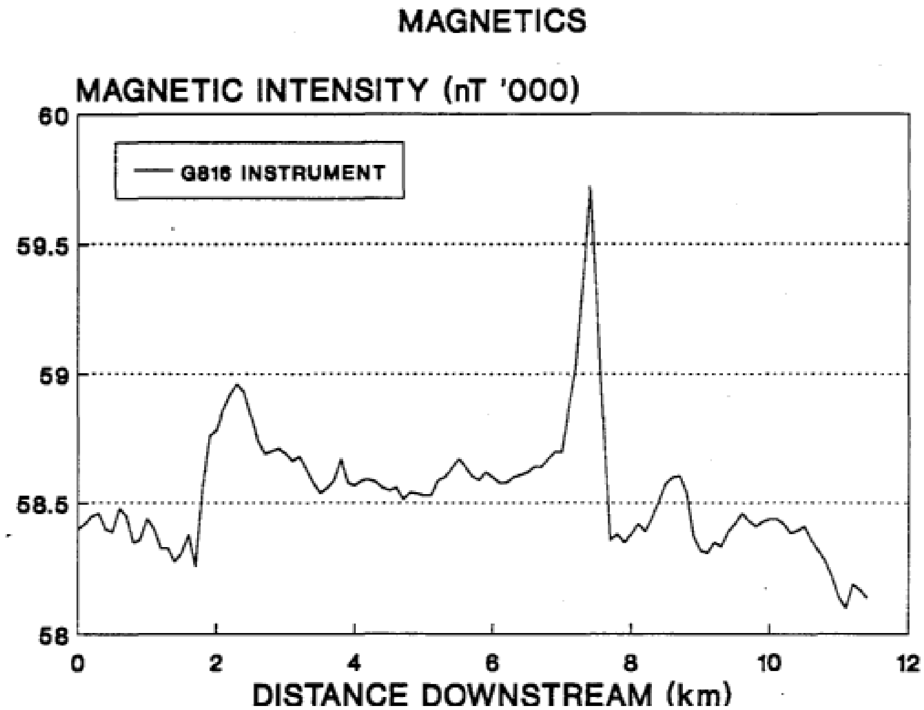
4.2.2 Electromagnetics

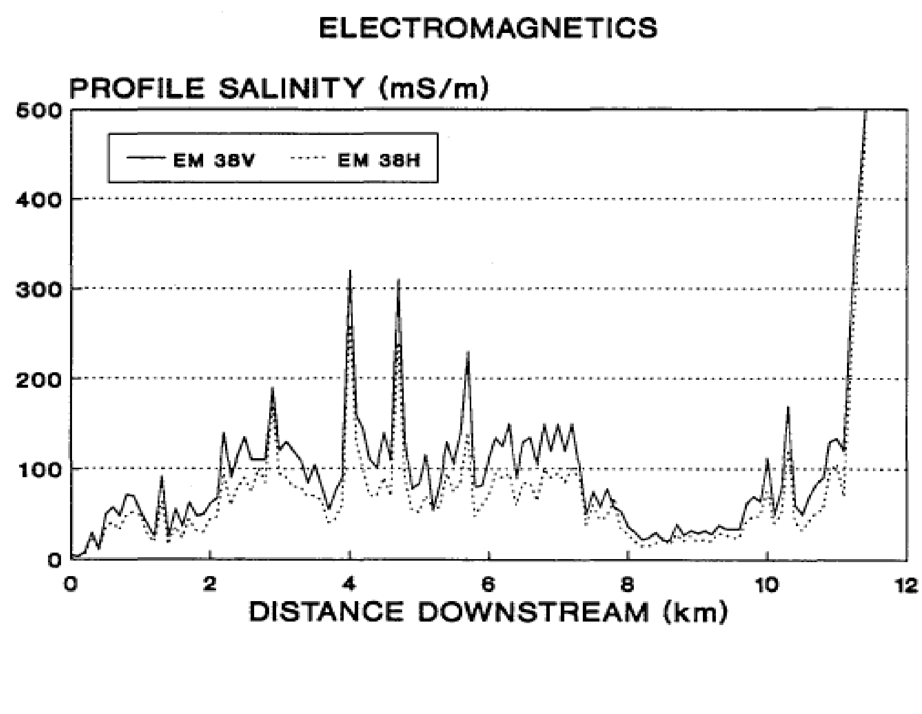
4.2.2.1 Welbungin Catchment

Measurements of the electromagnetic characteristics of soil and subsoils were conducted on a transect previously described above, and by taking geophysical soundings over individual boreholes. Figure 5 displays the trend of the EM3S survey data across the Welbungin catchment. Values of terrain conductivity (salinity) were noted to increase rapidly from non—saline outcrop areas in the east, to higher values (200 to 300 mS/m) west of the Welbungin South Road. Peak values were recorded in circular depressions with gilgai microrelief (crabholes) associated with localized waterlogging. However, the significant depth to groundwater (> 20 in) and the existence of salt-sensitive plants, suggest the high values are related to the high soil clay contents (Williams and Hoey, 1987), water ponding and soil structural degradation.

Further down the catchment values stabilize at approximately 100-150 mS/m, falling quickly (20 to 40 mS/m) towards the magnetic anomaly (Figure 5). The decrease in terrain conductivity could be due to effects brought on by the anomaly, however, it is more likely that lower salinities are the result of low salt storage (and clay content) in the sandy, deltaic sediments described in Section 4.1.1.1.

Figure 5


MAGNETICS
MAGNETIC INTENSITY (nT '000)
G816 INSTRUMENT
60
59.5
59
58.5
58
0
2
4
6
8
10
12
DISTANCE DOWNSTREAM (km)


ELECTROMAGNETICS
PROFILE SALINITY (mS/m)
EM 38V
EM 38H
500
400
300
200
100
0
0
2
4
6
8
10
12
DISTANCE DOWNSTREAM (km)

In the final 1,500 in surveyed, the traverse crossed aeolian parna (morrell soils) and ended adjacent to the palaeodrainage channel. Extremely high conductivities (> 500 mS/m) were recorded. High values were also noted in wind eroded and degraded sections of the farmland, in contrast to lower values on dunes along fencelines and in cereal stubble. Degraded (eroded) morrell soils had higher terrain conductivities than non-degraded areas.

Table 4 shows the results of borehole soundings conducted with the EM38 and EM31 on the Welbungin catchment. The values can be compared with information on the depth to the water-table and groundwater salinity. In the region above W207, EM38 and E1431 values are well correlated, although the BM31 values are higher due to the greater depth of influence (see Section 3.2.2). Below WBO8 a poor correlation was observed between EM recordings, depth to water-table (SWL) and groundwater salinity. Total dissolved salts (TDS) in groundwater is well correlated with depth to the water—table (SWL) (r^2 = 0.85).

TABLE 4. Comparison of Electromagnetics, Water Quality and Depth

1. Welbungin Catchment (6.11.1987)

BORE NO.	GEOPHYSICAL METHOD		DEPTH TO WATER-TABLE	WATER QUALITY
#	MS/m EM38	ECa EM31	SWL (m)	MS/m EC*
	H / V			(28.8.86)
WB01	21 / 17	63	-	-
WB02	7 / 0	42	-	-
WB03	86 / 38	98	(17.00)	N/A
WB04	160 / 80	198	-	-
WB05	34 / 10	100	-	-
WB06	38 / 12	66	-	-
WB07	3 / 1	62	-	-
WB08	18 / 4	120	5.07	3,770
WB09	140 / 120	210	3.64	3,720
WB10	100 / 40	120	3.42	3,880
WB11	155 / 110	220	3.81	4,730
WB12A	135 / 72	198	1.17	8,330
WB12B	121 / 63	200	1.39	7,220
WB13	170 / 140	210	3.44	4,070
WB14	70 / 30	151	1.10	7,310

H = Horizontal dipole (EM31 “6 m depth of penetration).

V = Vertical dipole.

* Conversion to mg/L TDS x 6.5 (to grains/gallon divide TDS by 14.3).

(17:00) Estimated before casing was run—in, 4 m lost near water—table.

4.2.2.2 Beacon River Catchment

Electromagnetic induction soundings were taken at each of the sites after drilling had been undertaken. Table 5 summarizes the results of the borehole profiling and presents the results from the water quality sampling and the depths to the water-table (SWL) for comparison.

The results broadly show that the highest salinities occur in association with salt-affected soils north of the Beacon-Burakin Road. Lower values occur downstream where the depth to the water—table increases. A wide variation in groundwater quality was observed in some of the bores over the period.

Discrepancies between salt storage and water quality measurements may have occurred due to the recharge of fresher runoff and rainfall, or conversely to concentration by evaporation of shallow waters during the summer.

Electromagnetic recordings are well correlated between the EM31 and EM38 (r^2 = 0.86), however, are not as well correlated with water quality (r^2 = 0.46) and depth to the water-table (r^2 = 0.38). Unlike the Welbungin catchment where only a small area was surveyed, a poor relationship existed between TDS and SWL (r^2 = 0.10) at Beacon.

TABLE 5. Comparison of Electromagnetics, Water Quality and Depth

2. Beacon River Catchment (4.11.1987)

BORE NO.	GEOPHYSICAL METHOD		DEPTH TO WATER-TABLE	WATER QUALITY	
#	MS/m EM38 H / V	ECa EM31	SWL (m)	MS/m	EC*
BE01	225 / 170	220	0.53	6,370	
BE02	270 / 110	200	0.32	6,130	
BE03	120 / 90	160	0.08	6,520	
BE04	85 / 50	144	0.12	6,220	
BE05C	100 / 80	164	0.32	6,170	**
BE05A	160 / 110	198	0.23	4,490	**
BE05B	180 / 110	220	0.31	5,320	**
BE06	200 / 150	220	0.05	4,170	
BE07	56 / 28	110	0.52	4,010	
BE08	270 / 240	270	0.14	6,150	***
BE09	180 / 140	190	0.42	6,050	
BE10	120 / 95	160	0.50	5,750	
BE11	58 / 24	130	1.07	5,550	
BE12	74 / 44	140	0.93	5,120	
BE13	28 / 10	100	0.97	6,140	
BE14	100 / 70	120	1.14	5,930	
BE15	17 / 4	68	0.84	1,490	

H = Horizontal dipole (0.5-2.0 m)

V = Vertical dipole (0.2—0.8 in)

* = Conversions mg/L TDS x 6.5 (to grains/gallon divide TDS by 14.3)

** = Sampled water quality 27/8/1986

= Bore not developed (see Table 8)

4.3 Soil and Groundwater Salinities

4.3.1 Welbungin Catchment

Soil samples taken during the drilling programme were intermittently collected for the analysis of variations of salt content with depth. Only four sites were sampled in the Welbungin catchment due to difficulties recovering samples caused by the dry, powdery nature of much of the profile. However, the limited results are presented in Table 6.

Soil salinities near the surface range from extremely saline at site WB13 to fresh to moderate in the remainder. The majority of subsoil samples were saline with the exception of upper 4 in of site WB13. Electromagnetic induction measurements taken with the EM31 correlated well with the soil sample conductivities over the 6 in depth of influence (r^2 = 0.70) and, therefore, can be considered to reflect salt storage.

Groundwater salinities were sampled on the 28.8.86 from each of the bores installed in the catchment. The results of the sampling (Table 4) shows a considerable variation between bore sites, increasing towards the valley floor and major drainage line.

TABLE 6. Soil Samples from the Welbungin catchment

SITE #	DEPTH (m)	EC (1:5) mS/m	SITE #	DEPTH (m)	EC (1:5) mS/m
WBO5	0 - 1	74	WB13	0 - 1	568
	1 - 2	166		1 - 2	411
	2 - 3	185		2 - 3	377
	3 - 4	182		3 - 4	344
	14 - 15	139		5 - 6	454
WB12A	0 -1	88	WB14	0 - 1	18
	1 - 2	159		1 - 2	109
	2 - 3	151		2 - 3	66
	3 - 4	205		3 - 4	98
	17 - 18	496		5 - 6	464

***** NB: Cereal production is reduced by 50-100% by EC values from 75—150 mS/m (EC 1:5).

4.3.2 Beacon River Catchment

Soil samples were also taken during the drilling programme, however, unlike the Welbungin catchment where the dry conditions produced difficult sampling conditions, extremely wet or silicified zones necessitated the addition of contaminants (drilling fluids and foreign water). Samples were only taken where contamination was considered to be negligible. The results are presented in Table 7, and reveal a similar pattern to the electromagnetic survey results presented in Table 5. Insufficient data were available to assess the relationship between electromagnetic induction values and drill samples as a method for remotely determining salt storage. Shallow zones show generally lower salinities than that at which occur at depth. This probably reflects the influence of winter recharge, moving salts towards lower levels within the sedimentary aquifers. Downward heads (recharge) were noted in a “bore—nest” at site BE5 during winter even though upward heads (groundwater discharge) was apparent in summer.

TABLE 7. Soil Salinities in the Beacon River Catchment

SITE #	DEPTH (m)	EC (1:5) mS/m	SITE #	DEPTH (m)	EC (1:5) mS/m	SITE #	DEPTH (m)	EC (1:5) mS/m
BEO1	0 – 2	125	BEO5	0 – 2	116	BE1O	0 – 2	142
	2 – 4	145		2 – 4	143		2 – 4	169
	8 – 10	431					12 – 14	299
BEO2	0 – 2	111	BEO6	0 – 2	107	BEll	0 – 2	39
	2 – 4	107		2 – 4	118		2 – 4	76
	10 – 12	325		8 – 10	235		12 – 14	324
BEO3	0 – 2	269	BEO7	0 – 2	63	BE12	0 – 2	100
	2 – 4	105		2 – 4	101		2 – 4	159
	22 – 24	281					12 – 14	153
BEO4	0 – 2	95	BEO8	2 – 4	121	BE13	12 – 15	290
	2 – 4	155		17 – 18	244		15 – 28	290
	6 – 8	240						
			BEO9	0 – 2	177			
				2 – 4	166			
				10 – 12	320			

Soil salinities downstream of the Beacon-Burakin Road generally show lower levels at both the shallow and deeper depths.

Groundwater samples were taken on four occasions during the study period to identify regional and temporal changes in salinity. The results are presented in Table 8. The data could suggest that groundwater salinities increased by approximately 10 to 100% over the period, with a mean increase of 1,500 mS/m. However, the increase may either suggest that evaporative concentration of the salts (equivalent to 100-200 mm of groundwater) has occurred, or that the bores had not been adequately developed following installation and the addition of drilling fluids. The latter cause is suggested since many of the bores are located in recharge areas, and the only two bores which show any consistency were known to have been well developed. Bailing of at least 5 to 10 times the casing volume is considered appropriate to reduce the risk of consequences of inadequate development.

TABLE 8. Groundwater Qualities – Beacon Catchment

BORE SITE	CONDUCTIVITY	DATE (ms/m EC at 25^{o}c)			VARIATION
#	**11.3.86**	**21.5.86**	**27.8.86**	**9.12.86**	
BEO1	4730	6300	6150	6370	+ 1640
BEO2	4690	4020	5580	6130	+ 1440
BEO3	5640	6520	6290	6520	+ 1060
BEO4	4380	6170	5630	6220	+ 1840
BEO5C	4720	4950	6170	6300	+ 1580
BEO5A	-	-	4490	-	-
BEO5B	-	-	5320	-	-
BEO6	4010	3470	4590	4170	0 1120
BEO7	4010	4220	5260	-	+ 1250
BE08	1300*****	5160	5790	6150	+ 950
BE09	4880	5150	5820	6050	+ 1170
BE1O	4330	4560	5310	5750	+ 1420
BE11	2930*****	4760	5680	5550	+ 2620
BE12	4130	4360	4900	5120	+ 990
BE13	3040*	5440	5980	6140	+ 3100
BE14	5070	5740	5780	5930	+ 860
BE15	1590	1590	1760	1490	0 270
			MEAN CHANGE		**+ 1500**

- = No Data Available + = Increase

0 = No Significant Change * = Lack of Development

Data recorded by the Geological Survey from 13 bores located north of bore BEO1 is shown in Table 9. Most bores were drilled in 1973, although two dry bores date back to 1928. The bore water quality data is significantly different to the zone south of BEO1, having a mean electrical conductivity of 750 mS/m or 4,800 mg/L (TDS) (330 grains). Bore yields average 10 kL/day (2,200 gallons/day). No indication is available from the drilling records of the location of the screens, however, the similarity between the estimated yields north and south of BEO1 suggest the majority of flow is from the sediments.

TABLE 9. Additional Drillhole Data

BORE LOCATION GSWA *	REFERENCE	TOTAL DEPTH	DATE DRILLED	YIELD kL/day	QUALITY ms/m
2,437 II	D 22	25	1973	9	580
"	23	28	1973	8	660
"	10	34	1973	> 15	290
"	19	34	1973	> 15	290
"	20	25	1973	> 15	290
"	21	25	1973	> 15	950
"	6	2	1928	Nil	-
"	8	5	1928	Nil	-
2,437 II	C 4	15	1973	11	1,070
"	5	32	1973	8	1,460
"	6	25	1973	5	850
"	7	18	1973	9	1,070
"	8	21	1973	9	800
TOTAL (and Mean Values)		**289 m**	**-**	**(10)**	**(750)**

* Data from Geological Survey of W.A. (unpublished archives)

The location of saline groundwaters south of the GSWA series occurs in the zone in which both active and inactive playa lakes are common throughout the valley floor. It is suspected that processes of lake development and brine reflux (the movement of saline-denser to depth) would be responsible (Bowler and Teller, 1986) for higher groundwater salinities in the downstream area.

5. Discussion

5.1 Salinisation, Flooding and Recharge

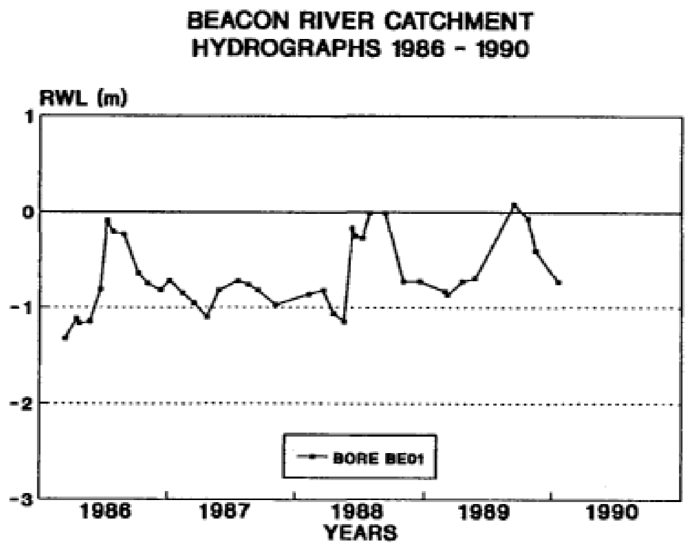
Extensive groundwater systems were well developed within both of the catchments before the clearing for agriculture took place. The existence of a deep, saturated profile to bedrock throughout the lower Welbungin and Beacon River catchments and historically active groundwater discharge mechanisms (playa lakes) between GSWA 4/8 and BEO8 at Beacon are clear evidence. However, the lack of any historical water - level data makes quantification of the effect of agricultural development difficult.

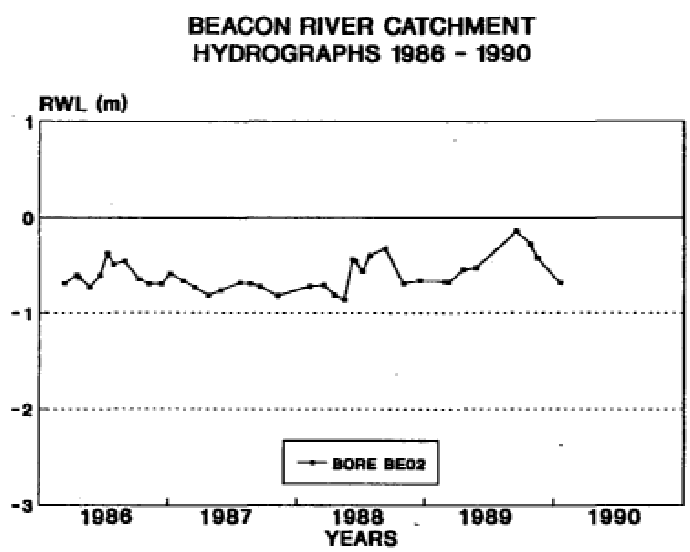
It is often assumed that recharge to the groundwater systems of catchments in the western wheatbelt, before clearing took place, was of the order of 1 to 5% of annual rainfall (George, 1986 and Peck and Williamson, 1987). However, in the eastern wheatbelt, George (in prep.), suggests that in the Welbungin and Beacon River catchments, recharge was probably only of the order of 0.01 to 0.10 mm/yr (or 0.003 to 0.03% of rainfall). Consequently, discharge rates were probably between 1 to 5 mm/yr, with losses occurring in isolated locations such as playa lakes and saline parts of the palaeodrainage lines. Although transpiration from the water-table could not be calculated, it should not be ruled out where aquifer qualities allow water to withdrawn from the water-table by phreatophytes (eg. eucalypts). Species such as E.salicola (salt salmon), E.longicornus (morrell) and E.loxophleaba (York gum) may be phreatophytic.

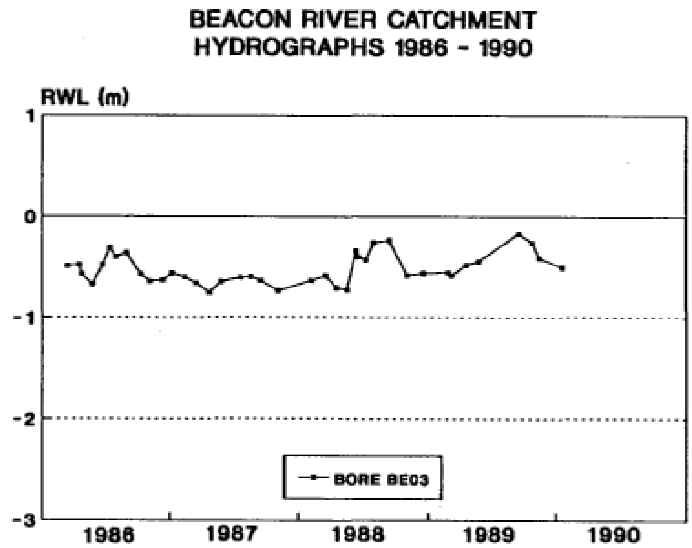
Recharge caused by agricultural development has been suggested to range from 10 to 100 mm/yr, depending on rainfall and hydrogeologic conditions (Bestow, 1976; Loh and Stokes, 1981 and Peck and Williamson, 1987). However, in the low rainfall and high evapotranspiration regions of the eastern wheatbelt, George (in prep.), considered that the long—term recharge rates are more likely to be of the order of 1 to 10 mm/yr.

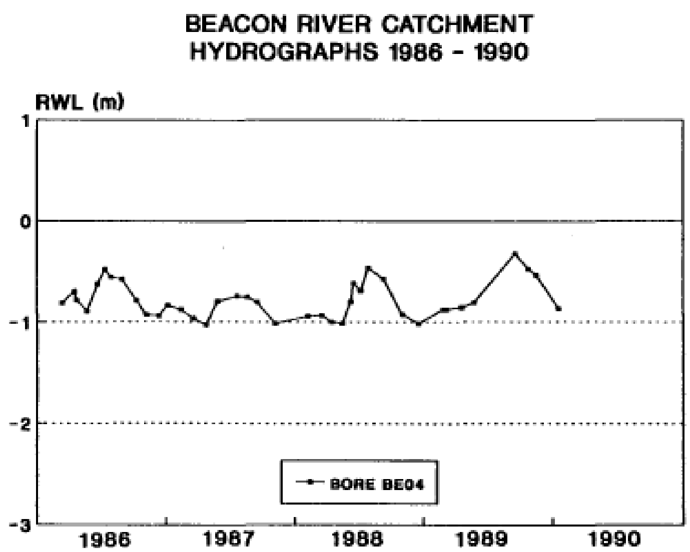
In the western wheatbelt, recharge rates (10 to 100 mm/yr) have usually been estimated by the specific yield technique (Bestow, 1976; Loh and Stokes, 1981; Peck and Williamson, 1987 and McFarlane et al., 1987). In the eastern wheatbelt specific yield of the. sedimentary semi-unconfined aquifers, estimated from local pump tests (George, in prep., b) were approximately 0.01 while in the western areas it was usually reported to be 0.05 (Loh and Stokes, 1981). Typical hydrograph responses from the Welbungin and Beacon catchments were of the order of 0.5 to 1.5 m. Resultant recharge rates using a specific yield of 0.01 are, therefore, of the order of 5 to 15 mm/yr. However, the recessions noted in most of the bores suggest that nett recharge, or the change in storage from year to year, was minimal. Estimates from bores which showed nett rises during the three year period 1986—1989, eg. (BEO1, BEO8, BE12, BE13) ranged from < 1 to 3 mm/yr. However, downward trends were noted in several of the Welbungin (especially WBO8A) and Beacon bores (BEO6) of a similar magnitude. Continued regular monitoring is suggested, to overcome the effects of seasonality (eg. 1989-1990) and to provide an accurate assessment of the likely development of salinity. It is important to recognize the negative effect of 1989-1990 periods (rising water-table) and positive impact of 1987 type years (lowering water-table) on hydrographs (Figure 6).

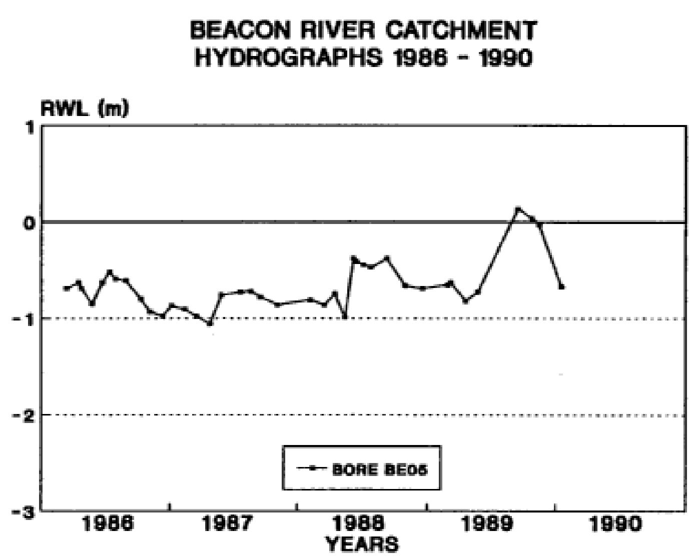
The resultant impact on the regional groundwaters of an increase in recharge from 0.01-0.1 to 1-10 mm/yr (1 to 4 orders of magnitude) should be very significant, resulting in large water-table rises (1 to 20 m) and the eventual salinisation of 5—15% of many wheatbelt catchments (Anon., 1988). However, the timing and magnitude of the salinity problem will be controlled by recharge and discharge rates, local hydrogeologic conditions and also by the water-table response times. The impact of the timing and magnitude of clearing the valley floors earlier in the century, and only relatively recent clearing of the sideslopes has been discussed for Darling Range catchments by Hookey et al. (1987) and Loh and Stokes (1981). Hookey et al. (1987) suggest that the establishment of a new equilibrium after clearing (in the Collie River catchments) may take tens to hundreds of years to develop.



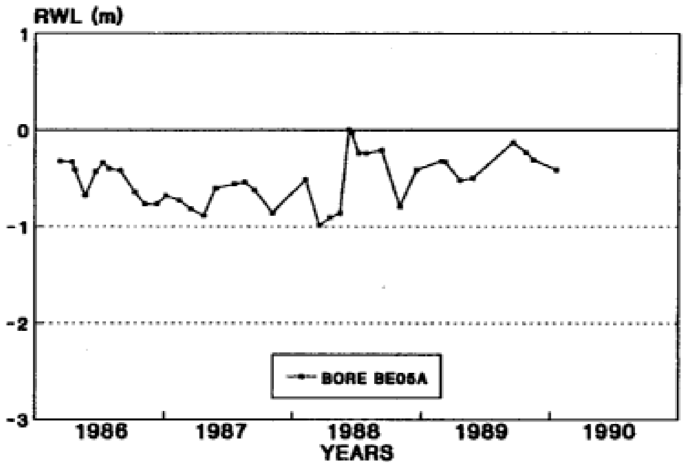



BEACON RIVER CATCHMENT
HYDROGRAPHS 1986 - 1990
RWL (m)
1
0
-1
-2
-3
BORE BE03
1986
1987
1988
1989
1990

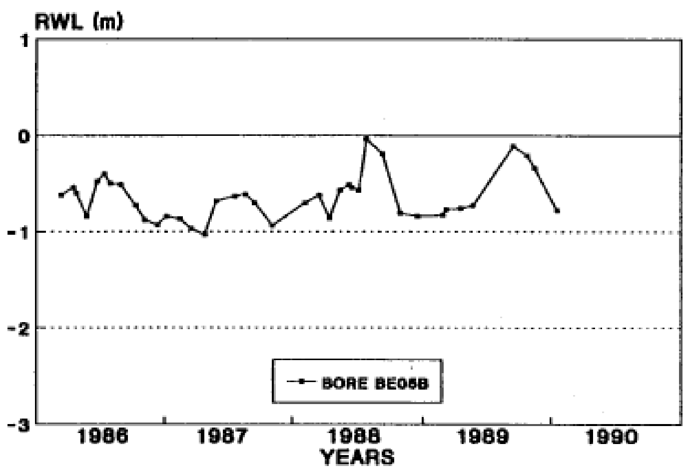

BEACON RIVER CATCHMENT
HYDROGRAPHS 1986 - 1990
RWL (m)
1
0
-1
-2
-3
BORE BE04
1986
1987
1988
1989
1990


BEACON RIVER CATCHMENT
HYDROGRAPHS 1986 - 1990
RWL (m)
1
0
-1
-2
-3
BORE BE05
1986
1987
1988
1989
1990
YEARS

BEACON RIVER CATCHMENT
HYDROGRAPHS 1986 - 1990



BEACON RIVER CATCHMENT
HYDROGRAPHS 1986 - 1990



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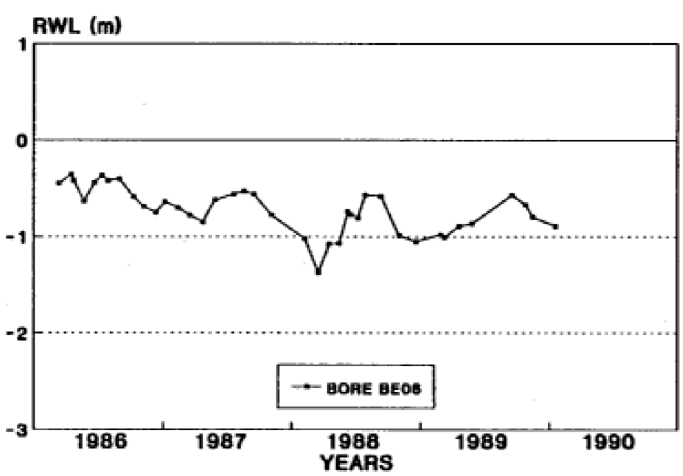
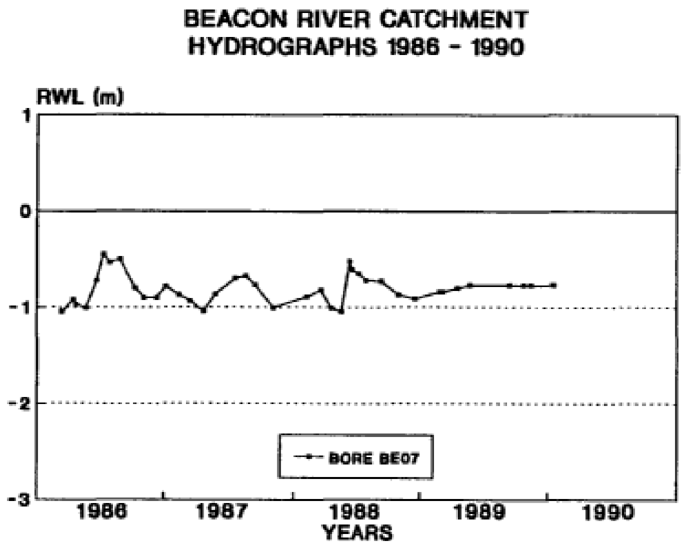
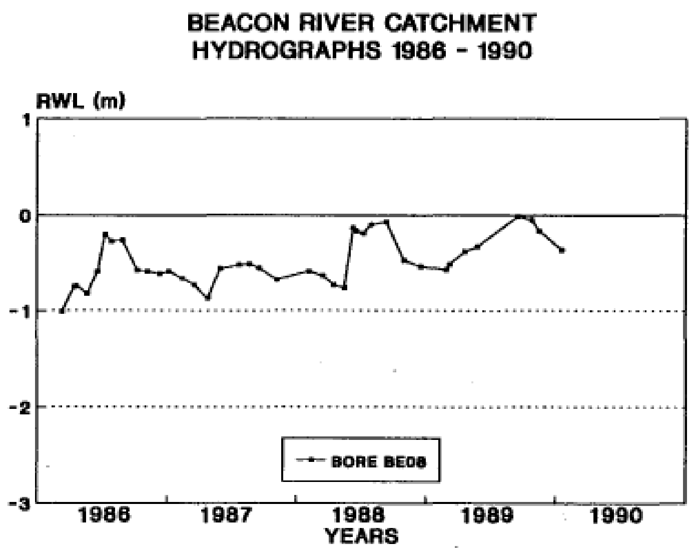
HYDROGRAPHS 1986 - 1990




BEACON RIVER CATCHMENT
HYDROGRAPHS 1986 - 1990
RWL (m)
1
0
-1
-2
-3
BORE BE07
1986
1987
1988
1989
1990
YEARS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HYDROGRAPHS 1986 - 1990
RWL (m)
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0
-1
-2
-3
BORE BE08
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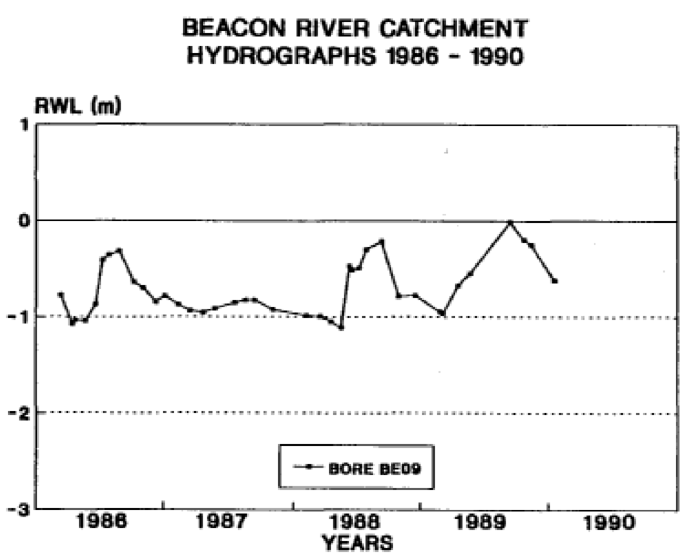
1987
1988
1989
1990
YEARS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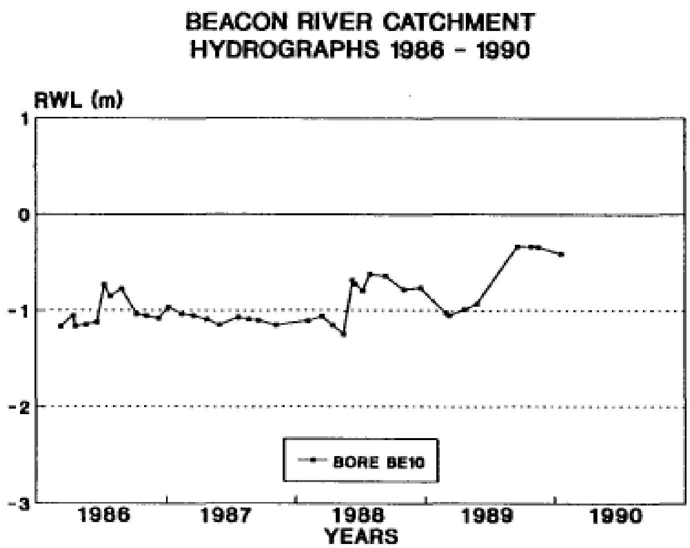
HYDROGRAPHS 1986 - 1990
RWL (m)
1
0
-1
-2
-3
BORE BE09
1986
1987
1988
1989
1990
YEARS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RWL (m)
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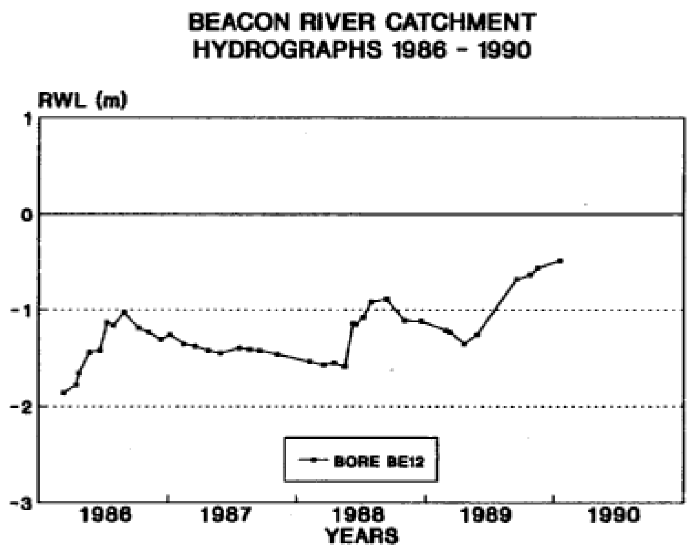
0
-1
-2
-3
BORE BE10
1986
1987
1988
1989
1990
YEARS


BEACON RIVER CATCHMENT
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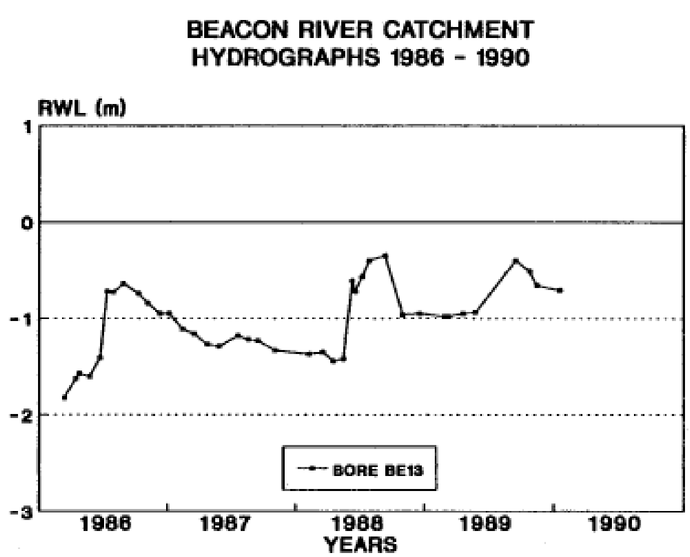
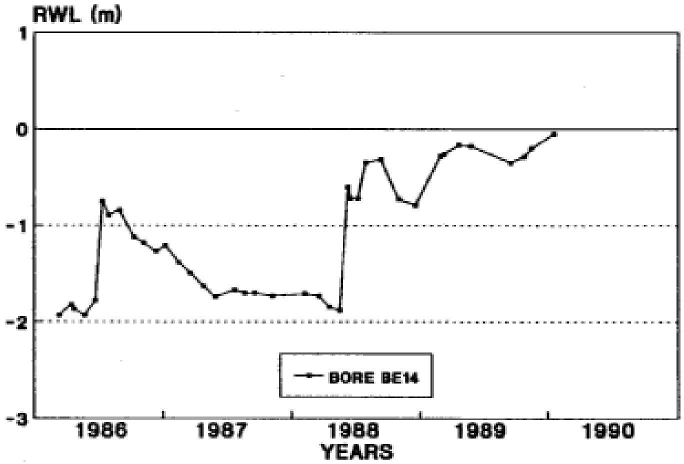
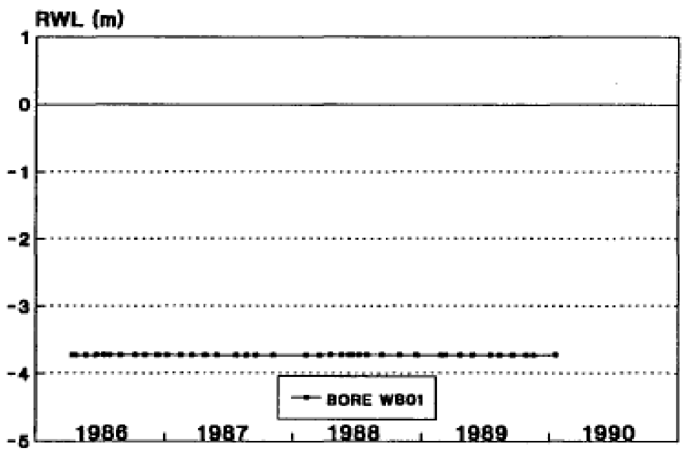
RWL (m)
1
0
-1
-2
-3
BORE BE12
1986
1987
1988
1989
1990
YEARS


BEACON RIVER CATCHMENT
HYDROGRAPHS 1986 - 1990
RWL (m)
1
0
-1
-2
-3
BORE BE13
1986
1987
1988
1989
1990
YEARS

BEACON RIVER CATCHMENT
HYDROGRAPHS 1986 - 1990



WELBUNGIN CATCHMENT
HYDROGRAPHS 1986 - 1990



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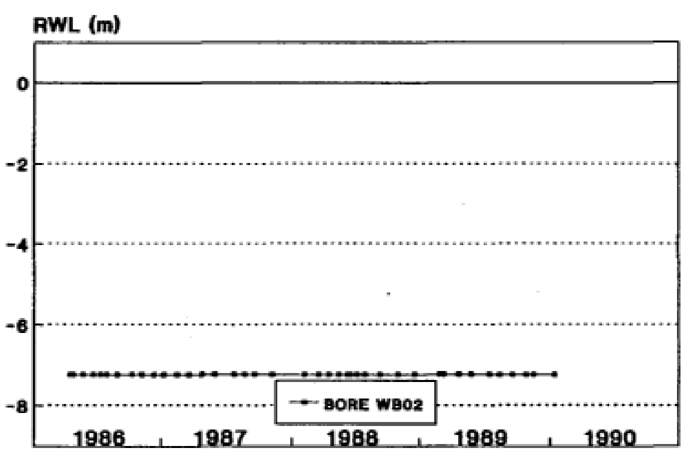

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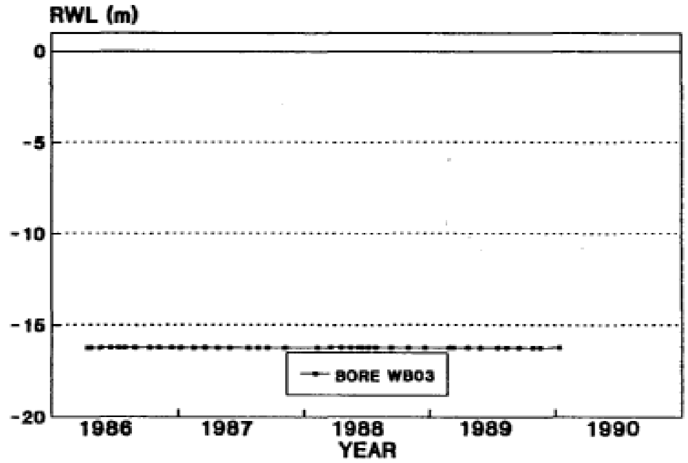

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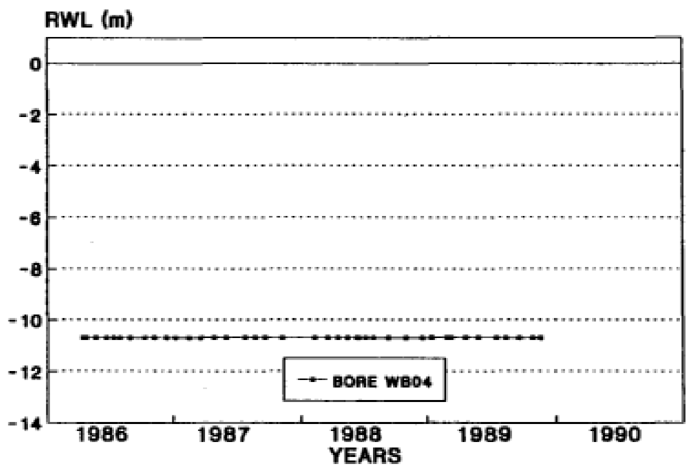
HYDROGRAPHS 1986 - 1990



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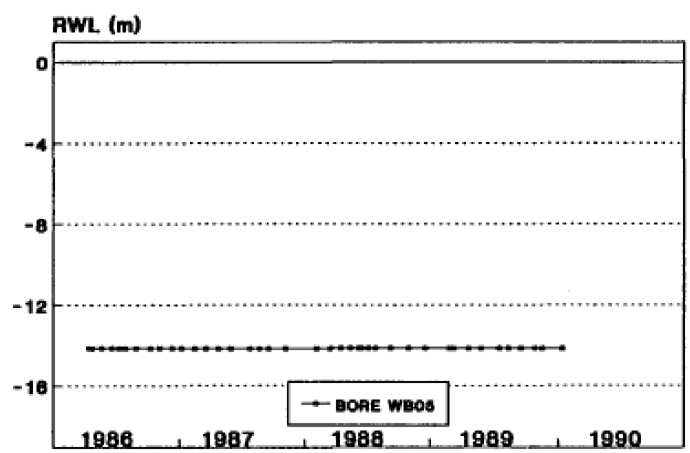
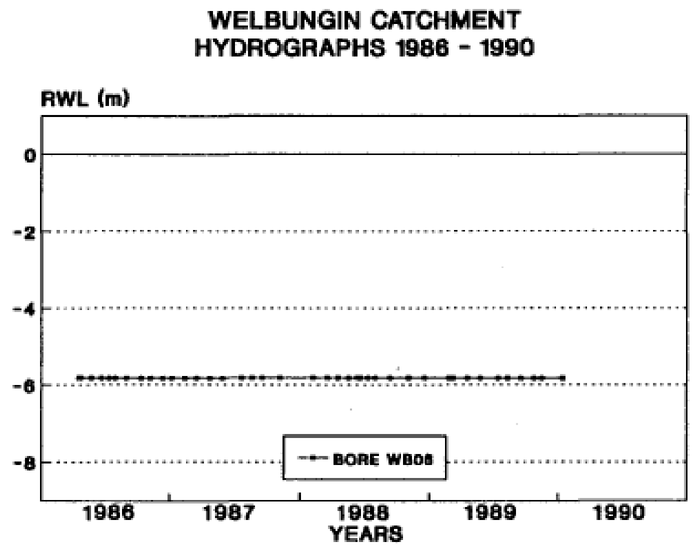
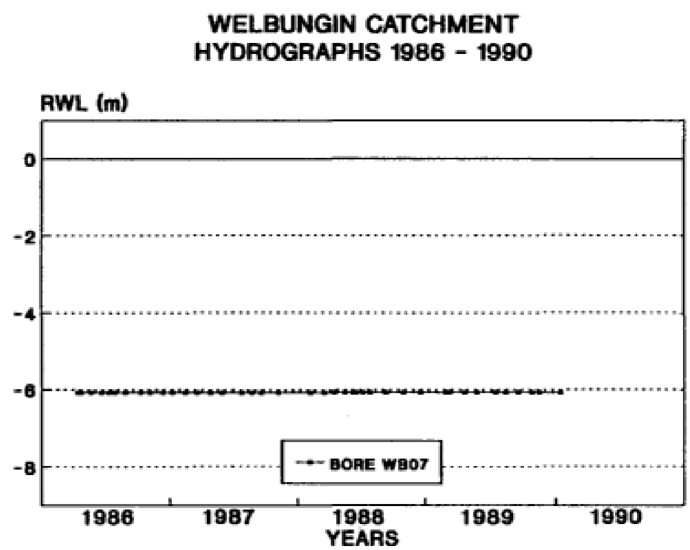
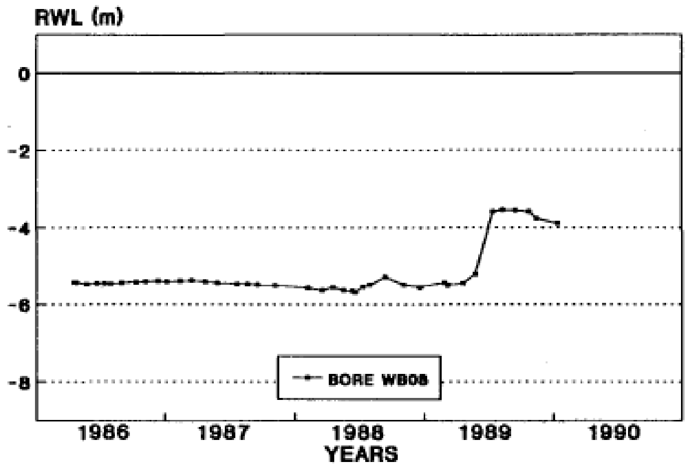


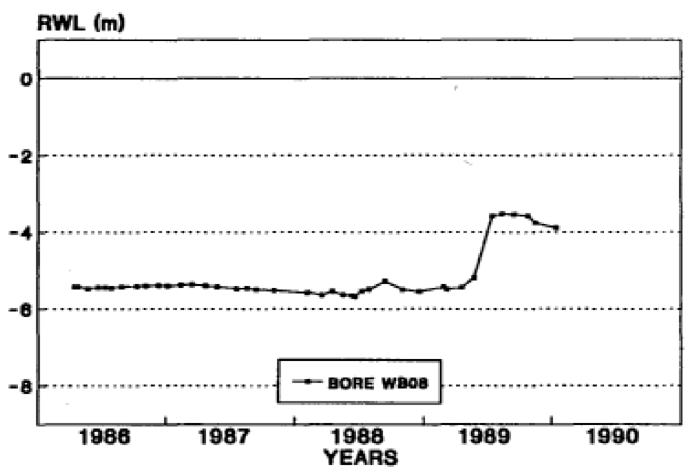

WELBUNGIN CATCHMENT
HYDROGRAPHS 1986 - 1990
RWL (m)
0
-2
-4
-6
-8
BORE WB06
1986
1987
1988
1989
1990
YEARS


WELBUNGIN CATCHMENT
HYDROGRAPHS 1986 - 1990
RWL (m)
0
-2
-4
-6
-8
BORE WB07
1986
1987
1988
1989
1990
YEARS

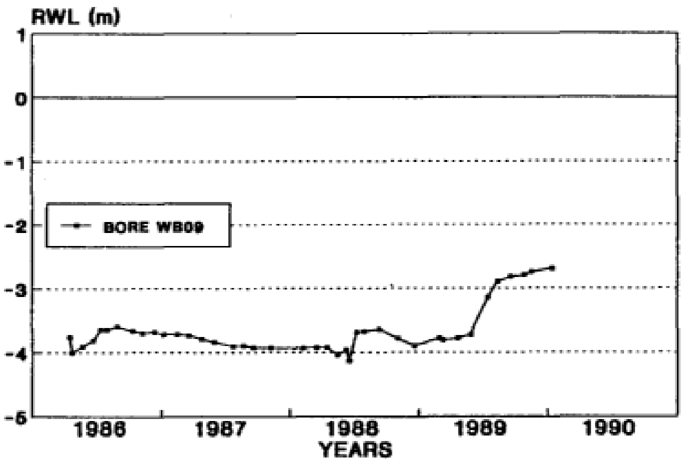
WELBUNGIN CATCHMENT
HYDROGRAPHS 1986 - 1990



WELBUNGIN CATCHMENT
HYDROGRAPHS 1986 - 1990



WELBUNGIN CATCHMENT HYDROGRAPHS 1986 - 1990



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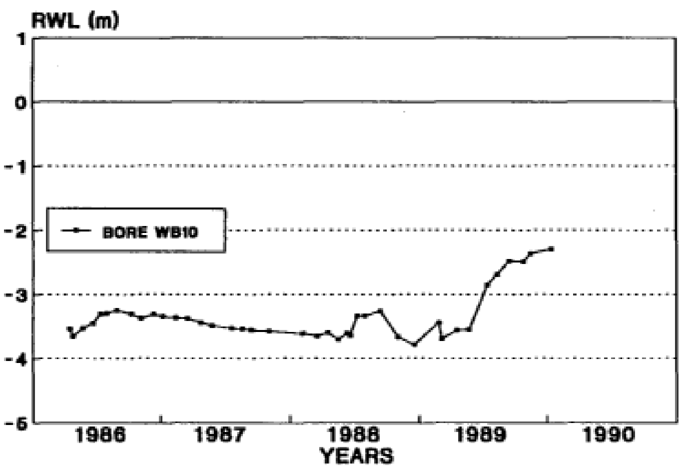
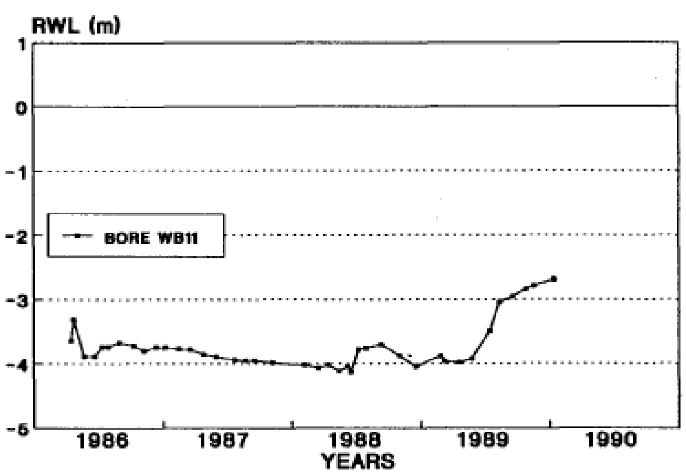


WELBUNGIN CATCHMENT HYDROGRAPHS 1986 - 1990



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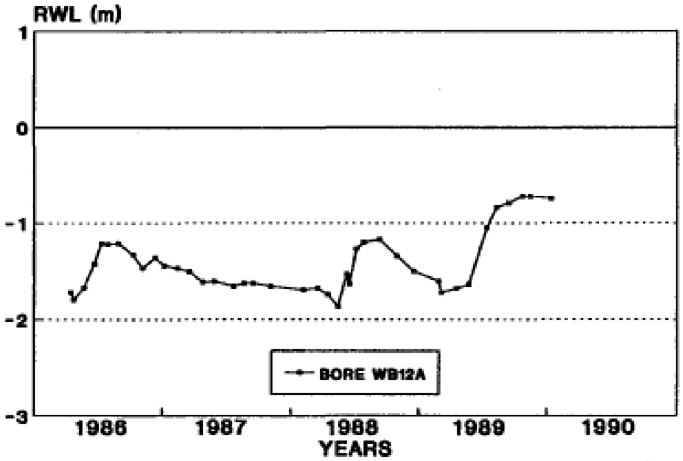
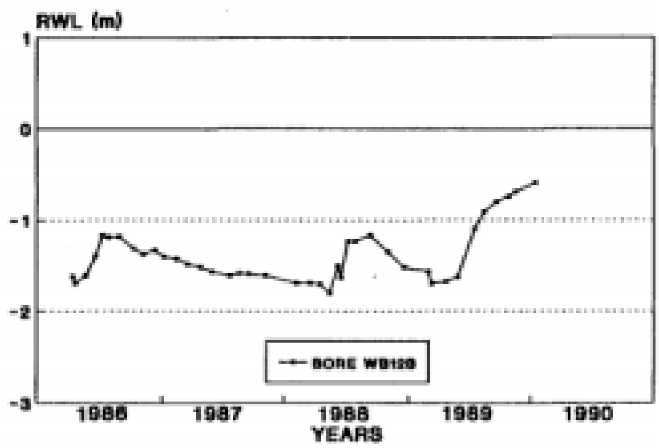
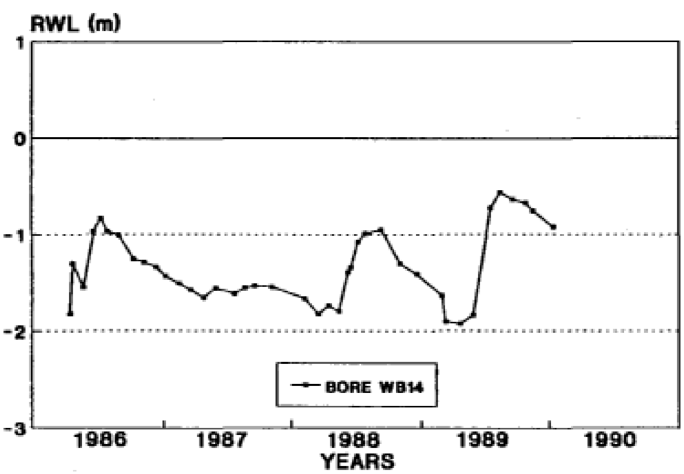
HYDROGRAPHS 1986 - 1990



WELBUNGIN CATCHMENT
HYDROGRAPHS 1986 - 1990



WELBUNGIN CATCHMENT
HYDROGRAPHS 1986 - 1990



Extrapolation of this evidence into the eastern wheatbelts suggests equilibrium may take hundreds or even thousands of years to achieve. Large catchments, low rainfall to recharge ratios and low hydraulic gradients are implicated as the reasons.

The hydrographs presented in Figure 6 shows that recharge occurs rapidly following the onset of winter rains. However, significant responses were only noted when waterlogging and localized flooding occurred on the valley floor. Smith (1962) argued that owing to the confined nature of wheatbelt aquifers, it was not possible to induce recharge from the waterlogging and flooding of the valley soils. However, Smith (1962) presents little hydrograph data to support his hypothesis. Similarly, he did not recognize the existence of deep sedimentary sequences (unconfined to semi—unconfined) such as those found in the two catchments described above. McFarlane et al. (1987) reported that waterlogging and localized flooding produce significant and rapid responses in water-table elevations, even below the heavy-clay textured Toolibin valley soils. McFarlane et al. (1987) noted that the shallow bores showed a marked decrease in salinity due to in-situ recharge processes. In 1988, bore measurements in the Beacon (BEO5) and Welbungin (W312) catchments also showed decreased salinities of 15 and 30% respectively following winter rains. The bores also display a seasonal reversal in the hydraulic gradients in response to the onset of rainfall and recharge.

The magnitude and changes observed in horizontal gradients also implies seasonal recharge takes place low in the landscape, even in areas of groundwater discharge. At Welbungin, horizontal hydraulic gradients (water-table) measured between WBO8 and WB12 in 1987 ranged between 1.4×10^{4} and -0.8×10^{-5}. The negative gradient implies that recharge from the palaeochannel area causes groundwater flow to take place <u>towards the recharge areas upslope</u>. If the salinity—density effects are taken into consideration the negative gradient strengthen ($-1.2 \times l0^{-4}$).

The implication that recharge rates are very low in the Welbungin catchment is validated by the poorly established regional gradients, the significant depth to the water—table and lack of any long—term trend in groundwater levels. Gradients at Beacon are significantly larger than those at Welbungin being equivalent to the valley floor gradient (2.5×10^{-4}) although upslope from BEO1 the gradient decreases.

6. Recommendations and Conclusions

6.1 Future Monitoring and Drilling

The hydrograph data discussed in Section 5 is ambiguous, since from 1986-1988 it showed that recharge, although significant in many of the bores, was being annually counterbalanced by discharge of a similar amount. As a result no clear picture of year to year changes has emerged. To overcome this problem it is strongly recommended that bore water—levels be monitored on a monthly to bi—monthly basis for a period of not less than five years (until 1995). The results gained from this monitoring will show whether or not salinisation will continue to develop in the study areas (WBO8-Bl4 and BEO1—BE15) and if so, when. Continued monitoring will also help determine whether the large rainfalls of 1989-1990 have had any lasting effect on water-tables within the valleys.

In the Beacon catchment, additional bores may need to be installed in the valley floor to the north of the current series. The main reason for this suggestion is that playa lakes observed between Barney Bore and Beacon—Rock Roads (and the flat nature of the valley north of Scotsman Road), are probably evidence that groundwater discharge has occurred in this region during previous geologic (Holocene—Pleistocene) times. Additional drill sites will provide information on the likely timing of salinisation, indicate its likely location and provide evidence for the sources of the recharge process responsible. Drill holes need only be drilled to the

water-table, a distance expected to be approximately 2 to 15 m below ground level. Drilling in the GWSA region is also recommended to determine the availability of groundwater supplies.

6.2 Management Systems

The management of saline soils can be conducted by two approaches. Firstly management systems can be developed to control recharge. The advantages are that in the longer term the eventual area of saltland and the magnitude of groundwater involved are lessened (Nulsen, 1984), while farm economics can be improved. In the second case, options available seek to increase discharge, thereby lessening the need for larger areas to become sites of groundwater discharge. In this case, drains, pumps or perennial and phreatophytic saltland trees and shrubs can be used to reduce or control the affected area. However, since nothing has been done to limit recharge, the discharge management systems must be operated permanently. A total or integrated catchment plan which seeks to combine a mixture of both recharge control and discharge enhancement measures is therefore recommended.

6.2.1 Discharge Management

Groundwater pumping from discharge zones, as a method of preventing salinity, has been attempted at other locations in Western Australia. However, in most situations effluent from the bores has been unusable and disposal problems have placed many of the projects in jeopardy. However, evidence derived from the GSWA bores, suggests that in the area north of the playa lakes (not south of GSWA 4/8) groundwater salinities are well within the established limits for livestock.

The availability of reasonable quality groundwater favours the groundwater pumping option. The aim of such a scheme would be to lower the water-tables in the region between GSWA 22/23 to GSWA 4/8, and reverse the groundwater gradient producing salinisation near BEO3 to BEO8.

Insufficient information is currently available to more closely assess the practicality of this option, however, it may provide a method of mitigating saltland development, preventing its northward movement and providing a useful water resource. If any groundwater extraction system was contemplated, water developed from production wells established on a grid network, would have to be able to be economically and legally moved to livestock watering points or areas for the disposal of excess discharge. Groundwater extraction may have to be continuous to maintain drawdowns of greater than 5 to 10 in, so that the horizontal gradients can be reversed.

A summary of the variety of agronomic and engineering options available for saltland management, for which technical advice can be sought, are given in Anon. (1988) and should be consulted for further information. Many of the management options discussed by Anon. (1988, 50-58 pp.) are based on the concept of limiting recharge, rather than preventing it altogether. The concept of “limited recharge” is based on the assumptions that unless perennial pastures, extremely efficient and high water using crops and agro—forestry systems are established, groundwater recharge will be higher than the pre-clearing levels. This in turn will produce a greater saturated thickness in the valleys and an increased area of groundwater discharge and salinity. The emphasis will be to minimize this area.

Drainage systems have been trailed at various sites in Western Australia to determine the effectiveness of tube, open, pumped well and biological (trees) drains. In the first three mentioned cases, drainage success is often limited due to the low permeability of subsoils in wheatbelt areas. However, drain spacings of 15 to 30 in, transmissive aquifers and tree plantations (Engel and Negus, 1988 and Bell et al., 1988) have been shown to work under some experimental conditions. In all cases preliminary investigations should be carried out and the economics of the systems proposed rigorously investigated. Economic and physically-based models are available to aid the decision making process (Salarian and McFarlane, 1987 and George, 1990).

In the Beacon River catchment, and to a lesser degree the Welbungin catchment, deep aquifer pumping may be technically feasible. However, it must be stressed that economic analyses and discharge disposal systems must be considered before a large capital programme is undertaken. Open and tube drains are also an option, however, variations in permeability in the upper 3 in, high salinities and disposal constraints limit its applicability. An integrated approach using both recharge and discharge management methods should be researched.

6.2.2 Reforestation

The use of trees as a method of lowering water-tables is usually limited by high groundwater salinities (> 10,000 mg/L), although recent advances in salt tolerant Eucalypt and acacia breeding programmes are likely to increase the salinity tolerance levels. Although the environment in the present discharge areas may be unsuitable, the potential exists to establish large areas of trees (phreatophytes) in the area north of the playa lakes where the groundwater salinities are much lower. If tree belts can be established across the valley that are capable of intercepting and lowering groundwater levels, of the order noted by Engel and Negus (1988) and Schofield et al. (1989) then they may provide sufficient discharge potential to mitigate the development of future salinity. The tree plantations could be used in conjunction with pumps as an additional method of groundwater extraction. This option (trees) should be actively considered as a research — demonstration priority as it appears to be a cost effective control.

6.2.3 Saltland Agronomy

A option which may both increase the rate of groundwater discharge and potentially lessen the spread of the salt-affected land, is the establishment of salt tolerant, halophytic plant communities.

These saltbush and bluebush “perennial” pastures are able to be grazed (Malcolm, 1986) and have been shown to be worth in the order of SA45/ha/yr to the farmer (Salarian et al., 1986). Establishment techniques have been improved and the need for autumn grazing areas on eastern wheatbelt farms makes it a viable option. Additionally, the interaction between the potential of profits from saltland agronomy and comparisons with the average yield of cereal and pasture systems, must be considered before drainage or alternative reclamation projects are attempted. Malcolm (1986) also notes that the discharge rates from halophytes are up to 20 times that from bare, unproductive saltland. Although there is still some debate over the effect of the impact of this, it is likely that the area of saltland would be restricted by revegetating salt-affected areas.

6.2.4 Flooding/Waterlogging Management

The control of surface runoff from degraded or runoff prone soils on the hillslopes in both Welbungin and, particularly, the Beacon River catchments needs to be addressed. It is acknowledged that some soils, no matter what their management history, are prone to runoff. However, within both catchments there are many soils which produce runoff as a result of the stock and tillage—rotation practices used. The use of level absorption banks, graded banks to waterways and dams and seepage interceptors may be appropriate in some circumstances, however, all seek to remedy the “effect” and not the “cause”.

Rotations which include long pasture phases may be responsible for soil degradation, including compaction, soil structure loss and hardpan formation. By contrast, some continuous cropping rotations, while not without some degree of associated degradation, do not appear to be responsible for producing as significant amounts of runoff. This is especially true of paddocks worked on the contour and fenced to appropriate soils and landforms.

It does not fall within the scope of this report to address these issues further. However, the popular belief in the Beacon catchment is that surface runoff control is the complete solution to land degradation. This is not borne out by results of this study. It does not follow from these comments that waterlogging and flooding do not have a major role to play in the process of groundwater recharge and the formation of salt-affected and degraded areas in the valley floor, as discussed above.

As an example, the development of recharge in the lower area (playa lakes) of the Welbungin catchment, causing groundwater gradients to induce flow back into the catchment (not the reverse as would normally be expected) indicates that flooding generated from different catchments can influence the development of salinity far away from the source area of the runoff. In this case, it may be necessary to look at management of the Lake McDermott-Beacon catchments as well that of the Welbungin catchment when addressing the potential of salinisation in the area.

A second example concerns the saline runoff which passes south of the Beacon-Burakin Road and infiltrates between BEO9-BE15. In this area the inflow of saline runoff and recharge to the sedimentary aquifer may lead to salinisation of the areas adjacent to the creekline. Management of this problem may require large scale salt tolerant eucalypt plantings on the creekline, improving the speed of water flow through the farmland or the prevention of saline discharge (other than flood—flows) from moving south of the railway line. These issues require further consideration by the Land Conservation District Committee.

6.3 ***Conclusions***

The hydrologic investigations in both the Welbungin and Beacon River catchments have indicated short—term requirements to control salinity.

They are to:-

1. Reduce flooding and waterlogging that is responsible for rapid and significant recharge of valley groundwaters.

2. Increase the water use (transpiration) of the catchment by introducing new rotations or modifying old ones. The fallowing of upland soils, structural degradation and unsuitable tillage systems produce higher levels of recharge than should be accepted. “Limited recharge” is essential.

3. Revegetate recharge areas along the main drainage line with trees to control accessions to the water—table and withdraw moisture from (above) it.

4. Drill further bores in the Beacon and Lake McDermott areas to determine the potential for the spread of salinity.

5. Consider various forms of discharge enhancement and saltland agronomy.

6. Research the implications of flood—runoff control structures in the catchment and their effect on salinity.

7. Consider a groundwater extraction system in the GSWA zone.

8. Assess the effect of saline runoff from the saline area (BEO5) on non-saline soils downstream (BEO9-BE12).

Catchment management groups are suggested for the Welbungin and Beacon River catchments as an appropriate structure for the development of integrated catchment management systems for the control of land degradation.

7. Acknowledgements

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The authors would also like to thank Messrs Davies and Dunne for local co-operation in each catchment, comments on the manuscript and the -support of the Mt Marshall Land Conservation District Group.

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WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO:	WB1/WB2	RIG TYPE:	R.A.B.
CATCHMENT:	Welbungin	CASING DEPTH:	5.12/7.64 (m)
DATE DRILLING:	March 1986	DEPTH DRILLING:	7.20/8.00(m)
LOCATION:	Capps/Proberts	QUALITY:	- mS/m
GRID REFERENCE:	30°52 ’40”N 117°59’8”E 30°52 ’38”N 117°58’50”E	YIELD:	- kL/day
		DEPTH TO BEDROCK:	-/- (m)
LAND UNIT:	Booraan/Merredin	SLOTTED LENGTH:	2 (m)
WATERTABLE DEPTH:	Dry/Dry (m)	SAMPLES:	Few

RESULTS

DEPTH (M) FROM	TO	DESCRIPTION OF BORE	ZONE
WB 1			
0	1.7	Mottled sandy clay. Decrease in qtz content and size with depth.	Mottled
1.7	-	Very dry sandy clay, becoming pallid with depth. Occasional haematite rich mottles. Last metre of profile became very hard, increased fresh minerals?	Pallid
7.20		Siliceous zone, no penetration.	
WB 2			
0	3.0	Fine textured sandy clay – clay loam over mottled, haematite rich sandy clay.	Sediments
3.0	-	Clay sands, medium texture (dry). Increasing clay content with depth.	Mottled
8.0		Drilling ceased on hardpan.	
Comments:		Bedrock not encountered on either hole	RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO:	WB3	RIG TYPE:	R.A.B.
CATCHMENT:	Welbungin	CASING DEPTH:	16.48 (m)
DATE DRILLING:	March 1986	DEPTH DRILLING:	17.0(m)
LOCATION:	Fazey	QUALITY:	- mS/m
GRID REFERENCE:	30°52 ’30”N 117°58’30”E	YIELD:	- kL/day
		DEPTH TO BEDROCK:	17.0 (m)
LAND UNIT:	Merredin	SLOTTED LENGTH:	2 (m)
WATERTABLE DEPTH:	Dry (m)	SAMPLES:	Few

RESULTS

DEPTH (M) FROM	TO	DESCRIPTION OF BORE	ZONE
0	0.5	Fine sandy clay loam (red/brown).	Sediments
0.5	-	Hard red/brown clays with minor quartz grit.	Pallid
3.0	-	Fine grey/brown clay sand grading to sandy clay at depth.	
12.0	-	Pallid sandy clay, fine qtz sands, occasionally mottled.	
17.0	-	Extremely dry. Dust from air rig blowing clay fraction away.	

Comments: Bedrock not encountered, no watertable RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO:	WB4	RIG TYPE:	R.A.B.
CATCHMENT:	Welbungin	CASING DEPTH:	10.95 (m)
DATE DRILLING:	March 1986	DEPTH DRILLING:	11.0 (m)
LOCATION:	Whyte	QUALITY:	- mS/m
GRID REFERENCE:	30°52 '27"N 117°58'20"E	YIELD:	- kL/day
		DEPTH TO BEDROCK:	- (m)
LAND UNIT:	Merredin	SLOTTED LENGTH:	2 (m)
WATERTABLE DEPTH:	Dry (m)	SAMPLES:	Few

RESULTS

DEPTH (M) FROM	TO	DESCRIPTION OF BORE	ZONE
0	0.5	Red/brown sands to clay sands.	
0.5	3.5	Red/brown, mottled clay – sandy clay with qtz and haematite rich pisolites (carbonate rich).	
3.5	7.0	Fine clayey sand, brown colour, qtz grounds sub-angular layering of mottles and grains.	
7.0	10.8	Grey clay sand, occasionally iron stained.	
10.8	11.0	Hard siliceous material. Chips of silica, with powdery clay matrix.	
		No penetration after 11m.	
Comments:		Bedrock not encountered. Silcrete stopped drilling	RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO:	WB5	RIG TYPE:	R.A.B.
CATCHMENT:	Welbungin	CASING DEPTH:	14.60 (m)
DATE DRILLING:	March 1986	DEPTH DRILLING:	15.0(m)
LOCATION:	Whyte	QUALITY:	- mS/m
GRID REFERENCE:	30°52 ’23”N 117°57’58”E	YIELD:	- kL/day
		DEPTH TO BEDROCK:	17.0 (m)
LAND UNIT:	Merredin	SLOTTED LENGTH:	2 (m)
WATERTABLE DEPTH:	Dry (m)	SAMPLES:	Few

RESULTS

DEPTH (M) FROM	TO	DESCRIPTION OF BORE	ZONE
0	0.5	Silty sand to red/brown clay sand.	Sediments?
0.5	4.0	Red/brown calcareous clay to sandy clay.	
4.0	8.0	Brown clay sands.	
8.0	13.8	As above (increased clay content).	
13.8	15.0	Extremely hard to drill. Silicified fragments in soil. 14.8 – 15.0 very hard siliceous hardpan. Outside temperature 46^{o}C, drilling rig over-heating (ceased drilling).	Hardpan
Comments:		Bedrock not encountered. Site near dyke.	RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO:	WB6/WB7	RIG TYPE:	R.A.B.
CATCHMENT:	Welbungin	CASING DEPTH:	6.11/7.00 (m)
DATE DRILLING:	March 1986	DEPTH DRILLING:	6.70/70.00 (m)
LOCATION:	Whyte	QUALITY:	-/- mS/m
GRID REFERENCE:	30°52 ’22”N 117°57’33”E	YIELD:	-/- kL/day
	30°52 ’25”N 117°57’02”E	DEPTH TO BEDROCK:	-/- (m)
LAND UNIT:	Merredin	SLOTTED LENGTH:	2/2 (m)
WATERTABLE DEPTH:	Dry/Dry (m)	SAMPLES:	Few

RESULTS

DEPTH (M) FROM	TO	DESCRIPTION OF BORE	ZONE
WB6			
0	0.5	Sandy clay loam.	Sediments
0.5	3.0	Calcareous brown sandy clay. Variously mottled. Medium grained little qtz.	
3.0	6.70	Brown-grey clay sands. Coarse sandy gritty fabric. Drilling quickly.	
	6.70	Pallid sandy clay, fine Hardpan (siliceous).	
WB7			
0	1.0	Brown sandy clay, silty sands.	Sediments?
1.0	4.0	Dry red/brown sandy clay.	
4.0	6.0	Grey/brown coarser sands to clay sands (moisture at depth).	
6.0	-	Grey clays – minor qtz (dry). Abandoned hole during dust storm which scoured 30cm out near rig – dangerous to continue. Possible water?	
Comments:		Bedrock not encountered, no watertable	RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO:	WB23	RIG TYPE:	R.A.B.
CATCHMENT:	Welbungin	CASING DEPTH:	18.55 (m)
DATE DRILLING:	March/April 1986	DEPTH DRILLING:	36.00 (m)
LOCATION:	Capp	QUALITY:	7720 mS/m
GRID REFERENCE:	30°52 '20"N 117°56'00"E	YIELD:	90-120 kL/day
		DEPTH TO BEDROCK:	36.00? (m)
LAND UNIT:	Nangeenan	SLOTTED LENGTH:	2 (m)
WATERTABLE DEPTH:	1.67 (m)	SAMPLES:	Few

RESULTS			
DEPTH (M) FROM	**TO**	**DESCRIPTION OF BORE**	**ZONE**
0	1.0	Fine sand to loamy silty clay.	Sediments
1.0	2.0	Red/brown sandy loam to silty clay.	
2.0	4.0	Clay sand.	
4.0	7.8	Layers of clay sand and washed quartzose sands. Rig making 10-20 kL/day. Subrounded pebbles/sands.	
7.8	8.5	Sands, mixture of qtz and feldspar.	
8.5	9.0	Minor red clays.	
9.0	11.5	Minor grey clays (30 kL/day).	
11.5	14.0	Red/purple clay sands.	
14.0	16.0	Qtz. Sands.	
16.0	18.0	Clay increased, drilling slow, hard grey clay.	
18.0	18.5	Hardpan – thick sloppy clay above siliceous zone (broken through after 20 minutes).	
18.5	27.0	Pallid sandy clay.	Pallid
27.0	31.0	Weathering.	Weathering

31.0	36.0	Saprolite grits, coarse feldspar, little quartz, red/brown fragments, iron rich mineral (gneissic) bedrock?	Saprolite
	36.0	Bedrock?	Bedrock
Comments:		Flow rate 90 – 120 kL/day - saline	RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO:	WB8,9,10,11,12,14	RIG TYPE:	R.A.B.
CATCHMENT:	Welbungin	CASING DEPTH:	As below (m)
DATE DRILLING:	March 1986	DEPTH DRILLING:	As below (m)
LOCATION:	Capp/Davies	QUALITY:	As below mS/m
GRID REFERENCE:	Central Point 30°52 '30"N 117°56'20"E	YIELD:	Too shallow kL/day
		DEPTH TO BEDROCK:	None (m)
LAND UNIT:	Merredin/Nangeenan	SLOTTED LENGTH:	2 (m)
WATERTABLE DEPTH:	Various (m)	SAMPLES:	Few

RESULTS

DEPTH (M) FROM	**TO**	**DESCRIPTION OF BORE**	**ZONE**
WB6		Total Depth 7.90 Quality, 3,770 mS/m	Sediments
WB9		Total Depth 5.12 Quality, 3,720 mS/m	
WB10		Total Depth 6.24 Quality, 3,880 mS/m	
WB11		Total Depth 5.78 Quality, 4,730 mS/m	
WB13		Total Depth 5.22 Quality, 4,070 mS/m	
WB14		Total Depth 6.45 Quality, 7,310 mS/m	
		Bores were drilled into a surficial zone of 3m, consisting of red/brown clay sands, over grey sands to clayey sands. Occasional siliceous hardpans.	
		Surface 2m calcareous.	
		Topsoil, 'Morrell' often saline.	
		Groundwater in all.	

Comments: Bores drilled to survey whether a catchment watertable to salt system gradient exists, or if it's the other way? RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO:	BE1, 2	RIG TYPE:	R.A.B.
CATCHMENT:	Beacon	CASING DEPTH:	11.54/11.52 (m)
DATE DRILLING:	Feb 1986	DEPTH DRILLING:	12.00/12.00 (m)
LOCATION:	Beagley	QUALITY:	6150/5580 mS/m
GRID REFERENCE:	30°24 '30"N 117°47'30"E	YIELD:	20/10 kL/day
		DEPTH TO BEDROCK:	- (m)
LAND UNIT:	Merredin	SLOTTED LENGTH:	2 (m)
WATERTABLE DEPTH:	0.81/0.60 (m)	SAMPLES:	Few

RESULTS

DEPTH (M) FROM	**TO**	**DESCRIPTION OF BORE**	**ZONE**
BE1			
0	2.0	Grey/brown clay sands – sandy clay.	Sediments
2.0	8.0	Red-brown sands to clay sands.	
8.0	12.0	Grey sand, some iron stained materials qtz pebbles in sand lenses where the drill bit – "drops through".	
12.0	-	Continuation of sands.	
BE1			
0		Brown loamy sand to coarse sand.	Sediments
2.0		Red/brown clayey sand.	
7.0		Grey clay sand, small coarse qtz gritty zones.	
11.0		Hard grey clay, very fine qtz. (Probably beginning of pallid zone).	Pallid

Comments: Flow 20 kL/day, saline (BE1) - sediments RJG
Flow 10 kL/day, saline (BE2) - sediments

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO:	WB3	RIG TYPE:	R.A.B.
CATCHMENT:	Beacon	CASING DEPTH:	20.95 (m)
DATE DRILLING:	Feb 1986	DEPTH DRILLING:	24.0(m)
LOCATION:	Beagleys	QUALITY:	6300 mS/m
GRID REFERENCE:	30°25'30"N 117°47'50"E	YIELD:	50 kL/day
		DEPTH TO BEDROCK:	- (m)
LAND UNIT:	Belka/Merredin	SLOTTED LENGTH:	2 (m)
WATERTABLE DEPTH:	0.48 (m)	SAMPLES:	Few

RESULTS

DEPTH (M) FROM	TO	DESCRIPTION OF BORE	ZONE
0	3.0	Brown sand.	Sediments?
3.0	6.0	Red/brown clayey sand to loamy sand.	
6.0	12.0	Grey clayey sand, tighter than above (although still coarser than a sandy clay). Developing water at 8 m.	
12.0	16.0	Grey brown sands to clay sands (decreased clay content). Fresh minerals present, qtz and feldspar.	
16.0	21.0	Medium – coarse red/brown sand. (Water to 50 kL/day). Very coarse at 20m.	Palaeochannel infill?
21.0	24.0	Hard grey clay. Siliceous hardpan at 21.0m. Fine pale clay and qtz. Pseudomorphs after feldspar, probably top of pallid zone.	Pallid
Comments:		Flow 50 kL/day (sediments) - saline	RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO:	WB 4,5	RIG TYPE:	R.A.B.
CATCHMENT:	Beacon	CASING DEPTH:	11.13/11.33 (m)
DATE DRILLING:	Feb 1986	DEPTH DRILLING:	12.0/12.0 (m)
LOCATION:	Beagleys	QUALITY:	5630/6170 mS/m
GRID REFERENCE:	30°25 '40"N 117°48'05"E	YIELD:	10 kL/day
		DEPTH TO BEDROCK:	- (m)
LAND UNIT:	Belka	SLOTTED LENGTH:	2 (m)
WATERTABLE DEPTH:	0.62/0.63 (m)	SAMPLES:	Few

RESULTS

DEPTH (M) FROM	TO	DESCRIPTION OF BORE	ZONE
BE 4			
0	0.15	Brown sand to loamy sand.	Sediments
1.5	6.0	Red/brown clayey sand.	
6.0	10.0	Grey clayey sand, sands medium grained moderately well rounded and sorted.	
10.0	11.0	Harder drilling, sandy clay. Very tight. Fine grained – pallid? Poor yield.	Pallid
BE 5		(3 Bores)	
0	2.0	Brown loamy sand.	Sediments
2.0	6.0	Red/brown clay sands.	
6.0	9.0	Brown, grey clay sands harder to drill with depth.	
9.0	11.0	Increasing clay content. Rapid decrease in qtz. Size.	
11.0	12.0	Hard grey sandy clay (Pallid zone a guestimate as we didn't drill on).	Pallid
		BE5 shallow slotted 0.2 – 2.20 Intermediate slotted 1.5 – 3.50	

		Both bores were drilled near the banks to determine the depth to the watertable, effectiveness of the banks (drainage effect). (Drilled in loamy sands – clay sands).	
Comments:		Yields poor, both < 10 kL/day – saline	RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO:	WB 6,7,8	RIG TYPE:	R.A.B.
CATCHMENT:	Beacon	CASING DEPTH:	17.47/AA (m)
DATE DRILLING:	Feb 1986	DEPTH DRILLING:	17.47/AA(m)
LOCATION:	Beagley	QUALITY:	4563/5260/5790 mS/m
GRID REFERENCE:	30°25 ’45”N 117°48’05”E	YIELD:	10 kL/day
		DEPTH TO BEDROCK:	- (m)
LAND UNIT:	Belka	SLOTTED LENGTH:	2 (m)
WATERTABLE DEPTH:	0.48/0.49/0.72 (m)	SAMPLES:	Few

RESULTS

DEPTH (M) FROM	TO	DESCRIPTION OF BORE	ZONE
BE 6			
0	1.0	Fine brown clay sand to silty sand.	Sediments
1.0	2.0	Brown clay sand.	
2.0	5.0	Red-brown sandy clay.	
5.0	7.0	Brown clayey sand.	
7.0	8.0	Sandy zone with occasional hard layers of iron cemented sands.	
8.0	-	Collective memory of drilling from here on suggests sediments to 10-12 m. Then pale grey sandy clay to17 m. Logs of hole lost – after 8.0m.	Pallid
BE 7	11.50	Same as BE06.	Sediments
BE 8	17.40	Same as BE01 and BE02. However drilled into ‘pallid’ zone at 13.0 – 15.0m. Clay sands above which are silicified.	Sediments Pallid

Comments: Little flow < 10 kL/day - saline. RJG